Monitoring Bluff Erosion Along Pennsylvania's Portion of the Lake Erie Shoreline

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Effective July 1, 1995, all references in this document to the Department of Environmental Resources shall instead be deemed to read the Department of Environmental Protection.

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1.0 Introduction

1.1. Study Purpose

1.1.1. Purpose of Current Study

The principal purpose of the current study was to document procedures for monitoring and calculating the rate of bluff recession on the Lake Erie shoreline in Pennsylvania. In addition, the current study involved remeasuring Department of Environmental Resources (DER) control points to provide data for computation of recession rates based on measurements made in 1982, 1985-86, and 1989. New technology with a potential for making future monitoring more efficient was examined and implemented where warranted. The degree and scale of new technologies developed to assist in locating, monitoring, and mapping control points and data associated with bluff erosion should be considered in context with past practice.

This document provides an update to the original work of the DER in 1974 which resulted in a study titled *Shoreline Erosion and Flooding: Erie County* (Knuth and Crowe, 1975). In that study, recession rates were established by measuring aerial photographs. The rates established by that study were used to delineate structural setback areas for the Lake Erie shoreline. The current study was done, in part, to reinforce or repudiate those rates based on direct measurement of shoreline control points over a twelve year time period.

This document provides a synopsis of work completed in the 1992-1994 phases of the current three year study. Included in the synopsis is a brief description of the purpose, results, and conclusions of work done during that time.

The document provides a summary of the significant factors of coastal bluff retreat for Erie County, Pennsylvania. This summary will be based on work detailed in Knuth and Crowe (1975) and Knuth (1983), (1985) and (1987). The summary will include a description of reach delineation described in Knuth, (1985).

The document provides a description of past efforts of DER to establish recession rates for Erie County.

The document provides the results of inquiries made of other Great Lakes investigators involved in monitoring bluffs and calculating recession rates. This description is supported by work authorized by the U.S. Army Corps of Engineers reported in Stewart, (1994).

Current efforts by DER to incorporate GPS/GIS technology is examined. DER authorized an examination of these methodologies in 1992-1994 for the purpose of discovering more efficient , more accurate, or more cost effective ways of monitoring and calculating bluff recession. The degree to which these new technologies meet these expectations is discussed.

The document provides a description of how DER control points are located and measured in the field. The description includes an estimate of how evolving technologies will be used in future field investigations.

Recession rate data based on seven to twelve years of direct measurement of DER control points is examined. Findings and an analysis of that examination are presented in the hope of providing useful information about bluff retreat for shore managers and property owners.

The document recommends additional work for DER to consider in its attempts to build a GIS data base for the coastal bluffs of Lake Erie in Pennsylvania.

1.1.2. Purpose of 1992-93 Studies

It has been twenty years since the first recession rate and coastal hazards study was completed for the study area. Advances in the ability of computers and other technologies to make tasks more efficient, store and manipulate data, and display and transmit information require an examination of how these advances apply to the problem of coastal zone management.

Although this study will focus on the application of various methodologies to recession rate studies and related problems, it is clear that these technologies may be expanded toward improving the ability of the Commonwealth to meet its responsibilities in managing the coastal resource.

There is a very practical reason for monitoring recession rates either in shoreline retreat or in bluff recession. Recession rates are used to establish hazard zones and setback ordinances to protect the resource and to prevent the loss of infrastructure, developed housing, or other structures. In addition, there is a compelling reason to understand, from a purely scientific point of view, the relationship among stratigraphy, geomorphology of the shore, and the natural forces of weathering and erosion on recession rates.

Efforts to determine recession rates in the Great Lakes are divided by institutional framework and geography. The amount of shoreline governed by the various Great Lakes States varies dramatically in length. However, they are easily categorized as States with very long shorelines and States with relatively short shorelines. The division is as follows:

- States with hundreds of miles of shoreline (Michigan, New York, Ohio, Wisconsin).
- States with relatively short shorelines measured in less than one hundred miles (Pennsylvania, Minnesota, Indiana, and Illinois).

The shorelines vary in geomorphology and physiography between low lying shorelines which are easily flooded and high rocky shorelines that are erosion resistant. Each shoreline type produces differences in recession rates, amount of hazard, and methods of studying these phenomena.

Extremes can be summarized as:

- Reaches of shoreline that are defined by massive, resistant rock shorelines with little or no measurable recession over time, and
- Reaches of shoreline consisting of unconsolidated sands and clays with recession rates that can exceed 1.5 meters per year.

In addition, shorelines can be categorized by the amount of development in the shoreline susceptible to erosion and flooding.

These categories vary between:

- Reaches of shoreline that are moderately to highly developed
- Reaches of shoreline that remain undeveloped due to ruggedness or remoteness

Shorelines are studied and managed by a variety of agencies from local government through international agencies.

By institutional framework, the division is as follows:

- Federal agencies with a legislative mandate that requires knowledge of shoreline characteristics (DOA, Corps of Engineers, United States Geological Survey, National Oceanic and Atmospheric Administration, Environment Canada)
- International agencies with a responsibility for consistency in reporting and regulatory function (International Joint Commission)
- State agencies with a mandate to manage the coastal resources (various State environmental agencies including DER
- Local governments with an interest in or a mandate for information gathering and/or management (Fairview Township, Erie County Planning Department)
- Other agencies at the State and Federal level with an interest in coastal zone management
  (Erie County Conservation District, Department of Agriculture Soil Conservation Service).

The length of shoreline, the degree of development, the relative recession rates or other hazard zone parameters and levels of governmental interest will dictate methodologies used to determine recession rates and hazard lines. In addition, the resources in money, time, and expertise available to an agency will dictate method and degree of investigation.

As a result of the above, methodologies developed and implemented have a wide range in variability. There is, however, a common thread throughout that is revealed in an investigation of them all.

That commonality is summarized as:

- Historical information in the form of maps, charts, and aerial photographs is the primary source of information to date
- Recession rates have been developed mainly by viewing aerial photographs with a stereo plotter or similar device. Information is transferred to a single map by hand or by zoom transfer scope, and recession is measured by digitizing the intersects of bluff lines and lines

drawn at right angles to the reach. The spacing of such measurement might vary from 100 feet to 500 feet. Some reaches in some states have been measured directly from surveyed control points. Pennsylvania remains the only state with recession rates based on direct measurement for the entire shoreline.

- The development of a geographic information system (GIS) is either in progress, or planned for the purpose of displaying, storing, analyzing and mapping recession rate information.
- While various methodologies exist for monitoring recession rates, each method requires the measurements to be repeated from time to time for verification.
- There is a universal problem with scale. The coastal zone, particularly that part of the coastal zone experiencing hazard is narrow (widths measured in tens or hundreds of feet) while the shoreline length is measured in miles. Recession rates can be measured in inches per year over a length of miles. This is a well recognized problem with respect to shoreline mapping.

Shoreline monitoring can be expensive in terms of manpower and time. A principal objective of the study was to determine if there exists a methodology that would make monitoring more efficient.

1.1.3. Recommendations Leading to Current Study

The results of the 1992-94 scopes of work are reported in Knuth and Lindenberg, (1994) The report recommended amending or rewriting the document *Shoreline Erosion and Flooding- Erie County* to incorporate a method of utilizing a combination of GIS and GPS technology to enhance the DER monitoring program.

The preferred method (of revision) is assumed to be a combination of an improved existing measurement methodology that will permit continued monitoring of shoreline recession and one using using ARC/INFO and GPS technology.

The basis of the document *Shoreline Erosion and Flooding-Erie County* was to provide the Commonwealth with an inventory of the Pennsylvania portion of the Lake Erie shoreline. This inventory was to establish the degree to which this shoreline was experiencing shoreline erosion and bluff retreat. Further, the inventory was to establish the hazard to existing structures.

This inventory is now twenty years old. During that time, shoreline erosion and bluff retreat have taken some toll on developed and undeveloped land. Much of the impact was predicted by the 1974 document; some was unforeseen. Shoreline development and consequent hard stabilization have also introduced negative impacts.

Recommendations for revision included:

- Existing aerial photography (ECPD's 911 orthophotography) at scales of 1:2400 and 1:4800 should be examined against older photography to permit a reach by reach analysis of changing patterns. Obvious areas of recent or advanced recession should be marked for examination in the field. (Verified information will be coded for input to the GIS)

- The maps included in the document should be produced from the GIS and should include at a minimum, information with respect to bluff height, bluff slope, hazard, 50 foot recession line, and sufficient landmarks as to make the maps useful to local municipalities and property owners. (For most GIS this amounts to printing to a plotter or similar device. Full scale maps as individual sheets could also be made available to municipalities.)

- Budget permitting, the document should continue to provide the basics of coastal geomorphology and information about shoreline protection and land use (and site) management.

- Tables, figures, and photographs should be updated.

- Geotechnical information including geomorphic information for mapping consistency with IJC, should be incorporated.

It would be possible to update the document using traditional methods.

Information gathered during this field season would be used to revise the document. All data would be displayed in tabular form and analyzed using simple statistical operations.

With the GIS, the document could be revised on a continuing basis as new information was added to the database. Tables, figures, maps, and charts would be available to property owners and coastal planners with very little time lapse between requests for information and delivery of a practical page or series of pages. The document would actually "live" in the GIS. Hard copies of the document would, of course, be available, but the document itself would be in a constant state of change. For example, new information about a particular reach may be developed as a result of a site visit. The new information is added to the GIS and changes would appear in various locations. Recession rates, hazard delineation, shore structure placement, change of ownership, major land use change are examples of information that would be updated in the GIS.

Revising the document in1994-95 is extremely important for a number of reasons. The existing document does not incorporate recession rate information gathered in 1982 and 1989. Land use changes in the coastal zone have been dramatic in many areas. Coastal hazards have materialized as predicted in some places, but not in others, whereas some areas predicted to be somewhat stable have proven to be more unstable than predicted. Information about the bluffs, beach and offshore bathymetry was not available in 1974. This information gathered over the past two decades and included in the revised document would greatly improve the consistency of reporting called for by the International Joint Commission.

Conducting field investigations, including aerial reconnaissance, compiling field reports for the last twenty years as well as incorporating recession rate studies and other studies would permit revision of the existing document and would enable the State to present a factual and up-to-date profile of the coastal zone with respect to recession rates and erosion hazard. While the revision is certainly necessary, it, too, will become dated and will need a major revision in a few years.

1.1.4. Conclusions and Recommendations of the 1992-94 Study

<u>Conclusions</u>

An evaluation of the current and potential methodologies for monitoring bluff recession for Pennsylvania's shoreline has resulted in the following conclusions:

- The current method used by Pennsylvania in measuring bluff recession and monitoring shoreline erosion is accurate.
- The assumption that available new technology would improve on the accuracy of the current method was not substantiated by the investigation.

- It was established that new technology substantially improves existing methodologies by making it easier to locate control points on maps or aerial photographs. (GPS)

- It was established that new technologies would make a profound difference in the way in which the DER manages information. (GIS)

- Pennsylvania has a record of historical recession rates for the entire shoreline based on direct measurement. While a few states have such a complete record, it is based on indirect measurement with percentages of error inherently higher than with a direct method.

- The data generated by monitoring recession rates has not been as usable as it should be because of inconsistencies in reporting and the potential for not recording active recession taking place between control points.

- All agencies queried as a part of this study, state, federal, and international, are in the process of incorporating some form of GIS into their program for obtaining and managing shoreline data.

- The document, *Shoreline Erosion and Flooding, Erie County* is out of date. It contains no current recession rate or hazard area information, and is not consistent with the needs of basin-wide management.

Recommendations

- Continue to monitor existing DER control points.

- Replace control points lost to development and supplement the 500 m control grid with points representing high recession rate areas falling between grid points.

- Incorporate global positioning system (GPS) technology to position control points either by plane coordinate system or by latitude and longitude. The system will permit easier location of the points in the field, finer location on map and/or geographic information system (GIS), and will permit the development of a linear representation of bluffline characteristics.

- Inventory existing shoreline conditions toward improving recession rate monitoring and hazard area identification.

- Hindcast recession rates for a sampling of high rate recession areas.

- Establish a geographic information system to manage and analyze existing data. This will make the data already available accessible for management decisions.

- Build a database beginning with digital orthophotography to include all information basic to coastal zone management decisions including land use, wetlands delineation, property information, and geomorphic relationships.

- Update existing orthophoto database with a new flight sufficient to produce digital orthophotography at a minimum scale of rf 1: 2400.

- Revise the document *Shoreline Erosion and Flooding, Erie County* to incorporate data and information gathered to date. The document should be a statement of the detailed work done by the DER since 1974 on recession rate and hazard zone monitoring.

1.2. Historical Overview

The Commonwealth of Pennsylvania has participated in the Federal Coastal Zone Management Program administered by the National Oceanographic and Atmospheric Administration (NOAA) since 1973. DER authorized a number of special projects designed to obtain information about the geology, physiography and geomorphology of the coastal zone. This information has been useful in administering the coastal zone management program. DER has specific responsibilities with respect to structural setback requirements in the coastal zone. A requirement for this regulatory function is knowledge of historical recession rates on the bluffs facing the open water shoreline of Lake Erie. Hazard zones, those areas where recession rates are above the long term historical average, are also of concern.

DER has additional responsibilities for which a knowledge of the geomorphological processes is important. Site visits to shoreline properties by DCP staff, consultation with shoreline developers, and responsibilities for monitoring the coastal resource, are examples of the need for this information.

To obtain recession rate information, the State began with a photogrammetric analysis of the historical recession rate for the Lake Erie shoreline. Selected control points were established on existing aerial photography and recession rates were developed by measuring distance differences over time. This work was done in 1974 and was reported in Knuth, (1975). The accuracy of the methodology was sufficient to provide justification for setback ordinances. Additional work was begun in 1981 to establish ground control points that could be measured over time to produce a more accurate recession rate for a representative point within a one kilometer grid alongshore. The methodology was expanded in 1986 to incorporate control points within a one-half kilometer grid alongshore.

Over the last twenty years, a surprising amount of information has been developed about the coastal zone, its geomorphic processes and its physiographic features as well as land use information. There is an increasing need to manage this information efficiently in the service of the public interest.

1.3 Regional Setting

The Erie County, Pennsylvania coastal zone is delineated by borders established in 1974 by DER and the Erie County Coastal Zone Steering Committees. The focus of this study is that reach of the coastal zone beginning with the Ohio-Pennsylvania border northeastward to the proximal end of Presque Isle peninsula and from the east channel entrance to Presque Isle Bay northeastward to the Pennsylvania-New York border. This delineation excludes Presque Isle peninsula, Presque Isle Bay, and the bluffs facing the waters of Presque Isle Bay. The lakeward extent is the outer limit of the nearshore zone to the landward area beyond the bluff crest. It contains the nearshore zone, the surf zone, the offshore beach profile, the onshore profile, the bluff toe, bluff face, bluff crest, and landward of the bluff crest to the limit of the long term recession line.

Section 2.0 Significant Factors in Lake Erie Bluff Retreat

There are several causal factors of bluff retreat. Many of the forms of mass wasting associated with steep slopes are present on the coastal bluffs of Erie County. DER has authorized reconnaissance studies of the Lake Erie shoreline bluffs. The results are reported in Knuth, (1983 and 1985). In Knuth, (1985), a discussion of bluff retreat was provided as technical support information useful for on-site evaluation of potential bluff erosion problems. The following is a synopsis of that information backed up with photographic examples. The photographs were taken in 1994 and all represent locations along the Erie County shoreline. (See plates, this section).

2.1 General Discussion

Slope movement is an expression of force overcoming resistance. Coastal bluffs are examples of systems in which force and resistance are continually opposed. Any change in environmental conditions can initiate downslope movement. When the forces within a mass overcome the resistance to movement, material will move. These forces require energy, and all energy in geomorphic systems is derived from either gravity or climate.

The force provided by gravity is simply the weight of the materials in the bluff including water and the external loads such as buildings or materials dumped on the bluff face. Shear force is a function of gravity and can vary on a bluff in any dimension. The factors that control it along any potential failure surface include slope, height, and weight of the materials. The addition of water to these materials reduces the resistance to shear.

Climate, through its control of water, air, and temperature, provides the energy for the most important forces on bluffs. Climate related forces include wind and wave action, surface and groundwater flow, rain impact, moisture and temperature related ground expansion, and ice action. Resistance to any of these forces is provided by the shear strength of these materials. Vegetation and structural controls (shore structures and bluff stabilization systems) may provide additional resistance.

Shear strength is not constant for any given material. It can change over time as weathering or ground water pressures interact with the climate factors.

The commonly encountered geomorphic processes on the bluffs include wave and current erosion at the toe of the bluff, wind erosion, and the action of ice, rain impact and sheet or rill erosion, groundwater sapping, sliding or slumping, solifluction, debris flow, and creep.

These process can be separated into two groups: mass movement and particle movement. In mass movement material begins to move as a coherent unit. If the movement of the mass is along a well defined surface without internal shear, it is termed a slide (or slump). If the shear is distributed throughout the mass without a clearly defined failure surface it is termed a flow. Movements in which particles move independently are called particle movements. Distinction between these categories is often difficult.

The following diagram illustrates the relationship of terms used in discussing mass wasting as a concept.

FORCES	GRAVITY CLIMATE	MASS MOVEMENT SLIDING ROTATIONAL SLUMPING TRANSLATIONAL BLOCK SLIDES FLOWS CREEP	PROCESSES
RESISTANCES	SHEAR STRENGTH VEGETATION STRUCTURAL SYSTEMS	PARTICLE MOVEMENT WAVE EROSION WIND EROSION ICE EROSION RILL/SHEET EROSION SAPPING	

Shear Strength and Shear Stress

Shear tress is the internal resistance that tends to prevent adjacent parts of a solid from "shearing" or sliding past one another parallel to the plane of the contact. It is measured by the maximum shear stress that can be sustained without failure.

Shear stress is a stress causing adjacent parts of a solid to slide past one another parallel to the plane of contact.

A discussion of the engineering criteria expressed as complicated formulae is outside the scope of this manual. No work has been done to determine the shear strength of bluff materials. It is known that shear stress overcomes shear strength in these materials. Much of the bluff failure along the Erie County shoreline is a result of this phenomenon. Ultimately, the DER will have to do engineering studies of these sediments to determine overall stability in the bluffs. This will allow some prediction about where slides are likely to occur and to what extent.

The actual stress at any point in these materials can be produced when 1) the soil becomes saturated and 2) loads are placed on the materials. When water enters sands and gravels, the loss of strength occurs immediately due to the high permeability in these materials. In clays and silts there is a lag because of low permeability. Increased stress is caused by placing a load on the soil surface, making an excavation in the soil or removal of part of the slope materials by erosion.

Mass Wasting

The effect of mass wasting on the bluffs is not well understood. An attempt is made here to briefly generalize this complex and very important process.

Sliding or slumping, flows and creep are listed as phenomena observed in the Erie County coastal zone. All are forms of mass wasting, a geologist's or geomorphologists term. An engineer refers to the same phenomena as landslides or slope movements. Types of movement are divided into five main groups: falls, topples, slides, spreads, flows, and creep. A sixth group, complex movements, includes combinations of the other five groups. These groups are related to the type or rate of movement. Materials are divided into rock and soil, with soil divided into coarse and fine grained. Soil, to an engineer, is anything that is not rock.

Slides, both rotational and translational, and flows are most commonly encountered on the coastal zone. Some falls are observed in the far western reaches but are otherwise uncommon.

Types of Slides

Slides are subdivided into rotational slides and translational slides. A rotational slide falls along a concavely curved rupture. The resulting slump surface is spoon-shaped and is rotational about an axis that is parallel to the slope. The classic slump is common in homogeneous materials. Rotational slides tend to occur in clayey soils and not in sands.

In translational slides (slumps) the mass progresses down and out along a more or less planar surface and shows no rotational or backward tilting characteristic of a rotational movement. A translational slump in which the moving mass consists of a single unit that is not greatly deformed is called a block slide (slump block). Translational slides can occur in a homogeneous mass. Granular materials such as sand and gravel fail in shallow slides with the failure surface parallel to the slope surface.

2.2 Reach Delineation

The Erie County shoreline can be divided into ten reaches based on physiography (Knuth, 1985). A topographic map of Erie County (scale 1:50 000) was scrutinized for physiographic similarities in a combination of bluff profile and upland features. Such features as might influence bluff physiography include drainage systems and glacial features such as beach ridges of former higher lake level stages.

Initially color slides of the entire shoreline were viewed to determine variations in bluff characteristics that influence bluff erosion. In 1994, a photo reconnaissance was made of the entire shoreline to provide visual clues concerning a range of bluff characteristics. These photographs were useful in substantiating the reach determinations made in previous studies.

Each reach exhibited an overall homogeneity. Though there were numerous variables with respect to bluff characteristics it was possible to establish ten major reaches. Within certain reaches it was possible to identify subreaches having a minimal linear alongshore extent. These subreaches are reported in Knuth, (1985).

2.2.1. First Order Delineation

The Erie County shoreline between the Ohio border to the southeast and the New York border to the northeast is 42.5 miles measured to exclude the Presque Isle spit. The spit would add approximately nine miles to the length of the shoreline. That part of the reach west of the proximal end of the spit to the Ohio border is twenty-five miles long. The distance from the entrance to Presque Isle Bay to the New York border is eighteen miles. The central reach is a combination of the lakeward and bay facing portions of the spit and the shoreline facing Presque Isle Bay. This reach is not part of the DER recession rate studies. No bluffs (except those cut by waves on the sandy beaches) exist on Presque Isle. The bluffs facing Presque Isle Bay are generally stable, protected from the erosional factors supplied by the open lake conditions east and west of the spit.

Bluffs may be characterized according to the following factors:

height
slope
slope geometry
stratigraphy
beach
human impact
degree and character of erosion on bluff face
recession at bluff crest

The reaches east and west of Presque Isle may be easily differentiated on the basis of a generalized description based on the above variables. A higher proportion of the bluffs east of the spit have a bedrock basement extending to as much as 20 feet above water level. This means that there are few beaches fronting these bluffs. Any sand accumulation occurs in small cuspate reentrants in the bluff. The bedrock bluffs are steeper and permit little vegetation to take root on the bedrock portion of the bluff. Bluffs west of the spit are generally higher with few having a bedrock basement. Consequently, these bluffs erode more easily at the base, depositing more sand into the longshore drift and creating protective beaches with a shallow profile. These differences in stratigraphy cause significant variations in the remaining elements. These two reaches are divided into ten major reaches

2.2.2. Second Order Delineation

A general description of the ten major reaches follows:

Reach 1. The New York-Pennsylvania border to one mile east of Sixteen Mile Creek.

The reach is defined by low bluffs approximately forty feet in height. Total local relief of the longshore profile is from 610 feet to lake level (573 feet, IGLD) at the mouth of Twenty Mile Creek. The bluffs vary in slope from very steep (forty-five degrees) to gently sloping (eighteen degrees). The slopes are linear in form with little evidence of differential erosion or slumping. The stratigraphy is extremely complex. While much of the face is masked by vegetation, exposed areas show some unusual sequences. Bedrock is lacking in the section but is apparent at the beach face, and shelves offshore over most of the reach. Siltstone lenses outcrop at these locations producing large flags and shingles. The basal unit is a clay till overlain by a sandier light brown layer (lacustrine?).

The bluff is incised by intermittent streams draining the upland. Bluff retreat is reduced in proximity to the stream mouths. Gully erosion in the bluff face is generally absent. With minor exceptions the beaches lining the reach are fairly extensive being at least twenty-five feet wide and continuous over the reach.

Reach 2- East of Sixteen Mile Creek to four hundred yards west of Sixteen Mile Creek

One of the most spectacular stratigraphic breaks of the entire shoreline occurs at the beginning of this reach. To the east, bedrock is just at water level or not in evidence at all. Beginning at this reach, bedrock comprises eight of the fifty feet of height. The exact contact is obscured in a small stream valley. Bluff height varies along the alongshore profile from fifty feet on the east to eighty feet on the west. The overall slope is steep from crest but is compound in nature; concave from crest to the bedrock contact with a steep seventy degree slope from that contact to the base of the bluff. The concavity in the slope is produced by differential erosion in the materials above bedrock. The basal till is prone to flow while the sandier layer on top is more prone to oversteepening and failing as minor slumps. The bedrock, resistant to erosion, displays a steep face to approaching waves.

Joints in the bedrock have been widened by the force of the waves to produce incisions of some size (up to fifty feet wide by twenty feet deep) in the shale. In these small coves sand accumulates and forms pocket beaches. Otherwise, there are no beaches forming except at Sixteen Mile Creek.

Reach 3- West of Sixteen Mile Creek to three quarters mile east of Twelve Mile Creek

The bluffs along this reach are the highest in Erie County to a height of 160 feet. In this section the beaches of glacial Lake Warren strike offshore. This massive thickness of beach sands and gravels is underlain by finer sands of lacustrine origin. These sands are in turn underlain by two distinct clay till layers. At the base bedrock is exposed, varying in thickness from four feet to ten feet.

The bluffs have eroded a complex face due to differential erosion in these materials. Large arcuate failures in the top sand layer are prominent. Beaches have formed but are not continuous. Where bedrock is exposed the beaches tend to disappear entirely.

Reach 4- East of Twelve Mile Creek to three quarter Mile east of Seven Mile Creek

This reach has a long shoreline length but is very homogenous throughout marked only by difference produced by the dissection of streams. The undulating surface of the bedrock exposures produces minor difference in the response of the bluff to wave attack. The bluffs vary in height from eighty to one hundred feet and are fairly steep with some slopes of forty-five degrees observed.

The stratigraphy varies greatly in the thickness of individual units, but four distinct units are present. The bedrock base undulates with a minimum exposure at the base to thicknesses of ten feet or more. The bedrock is overlain by two distinct till units, possibly three. Where bedrock exposure is minimal, the basal unit is exposed and with resultant oversteepening. Above these clay units is a sandy unit prone to slumping. The beaches are discontinuous over the reach and disappear entirely where bedrock is exposed at the base of the bluffs.

Reach 5- Three quarter mile east of Seven Mile Creek to International Paper Company

This is the largest homogeneous reach east of Presque Isle. The longshore profile varies very little in height above lake level, usually close to 640 feet above IGLD. The bluff angle varies dependent on the amount of bedrock exposed. The bedrock exposures tend to be steeper than fifty degrees, while the clay layers above take on a more gently sloping profile. Bedrock is exposed over much of the reach. The surface undulates, but very gently. Joint sets in the shale govern the orientation and the sizeof the incisions made by the hydraulic expansion of wave pressure striking the bedrock outcrop.

The bedrock is overlain by a thin mantle of till. In some places there is evidence for a second unit. The reach is marked by the prominence of the bedrock exposure. The bedrock -clay interface is swept by overtopping waves producing a narrow shelf at the top of the shale layer. Above this contact, wave energy erodes the base of the till unit and produces recession at the crest.

Reach 6- Proximal end of Presque Isle spit to east of Walnut Creek

The bluffs to the east of Montpelier Avenue are more or less protected by the broad beaches at their base. This is particularly true from the Baer Farm area east to the beginning of the spit. The bluffs here are well vegetated, although the face of the bluff exhibits characteristics of slumping that must have occurred at least fifty years ago. There are a few spots where recession can be traced, and these sites are generally associated with poor land use management.

The bluffs are of constant height over the entire reach. The basal unit is shale the surface of which undulates to a maximum exposure of eight feet to a minimum exposure just at mean water level. There is very good correlation between beach formation and the absence of bedrock exposure. There are two, sometimes three distinct units overlying the shale. The bottom two are almost certainly tills while the top layer is lacustrine in origin. The sandy top unit varies in thickness and has eroded into a series of serrate forms. There is some evidence that these gullies "migrate". New ones form adjacent as the old ones heal. Healing is attributed to the more stable angle produce between the head of the gully and its base.

Reach 7- East of Walnut Creek to one mi. west of Godfrey Run

This is a continuation of the general characteristics of Reach 6 previously described. Walnut Creek provides a major interruption of the shoreline bluffs at this location between the stream mouth itself and and the wide shoreline beaches of the Manchester Beach area. Where beaches narrow once more west of Walnut Creek to near Godfrey Run, the bluffs are essentially the same as to the east of Walnut Creek.

Reach 8- Erie Shores Development to one-half mile west of Elk Creek.

The sandy beach deposits of glacial Lake Warren are much in evidence along this reach and produce much of the more spectacular bluff erosion events. The bluffs along this entire reach are very prone to slumping and multiple slumping events are noted at some of these sites.

The sandy layers are underlain by the same till sequence observed in Reaches 6 and 7. Bedrock is not exposed along this reach, but the presence of shingles on the beaches indicate it is exposed just below mean water level. The basal units are clay layers which are very prone to flow during the thaw and runoff cycles in the spring. This wasting of material at the base sets these slopes up for the oversteepening necessary for the shear strength in the sands above to fail. This produces massive slump blocks.

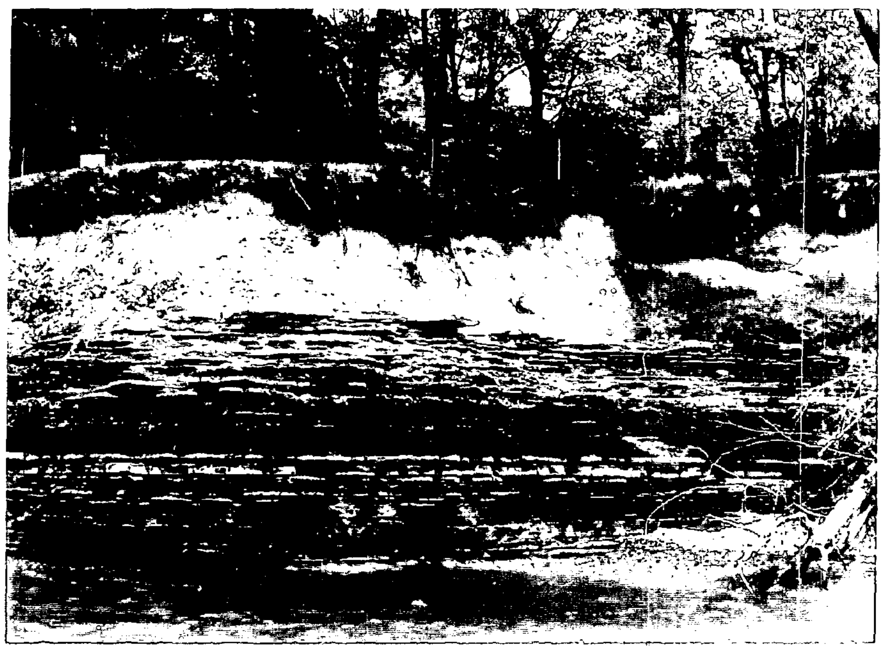
The downcutting of Elk Creek and the changes in the channel have produced a terrace to the east of the stream mouth. The exposure here is a single clay unit that causes the bluff to retreat at a fixed slope angle over time.

Reach 9- West of Elk Creek to East of Crooked Creek.

The bluffs along this reach vary little in height above lake level, about 650 feet. The face is deeply incised by gullies on the relatively steep bluff slope. Bedrock is present just below the surface in most places. The basal clay unit is exposed to wave attack, producing wave notches at the toe of the bluff. Oversteepening and the effects of sapping are producing some significant erosion in these bluffs.

Reach 10- Crooked Creek to the Pennsylvania Border with Ohio

This reach is most marked by the amount of variation exhibited over the reach. At Crooked Creek, the bluffs are low lying and prone to wave attack and subsequent oversteepening. Rising further west, the bluffs pick up an additional clay layer . The character of the basal tills changes at Raccoon Creek. The clays are more cohesive and failure in them tends to produce columnar failure producing blocks of some size. Recession here is very rapid, producing bluffs of high angle.



Plates

Photo # 1

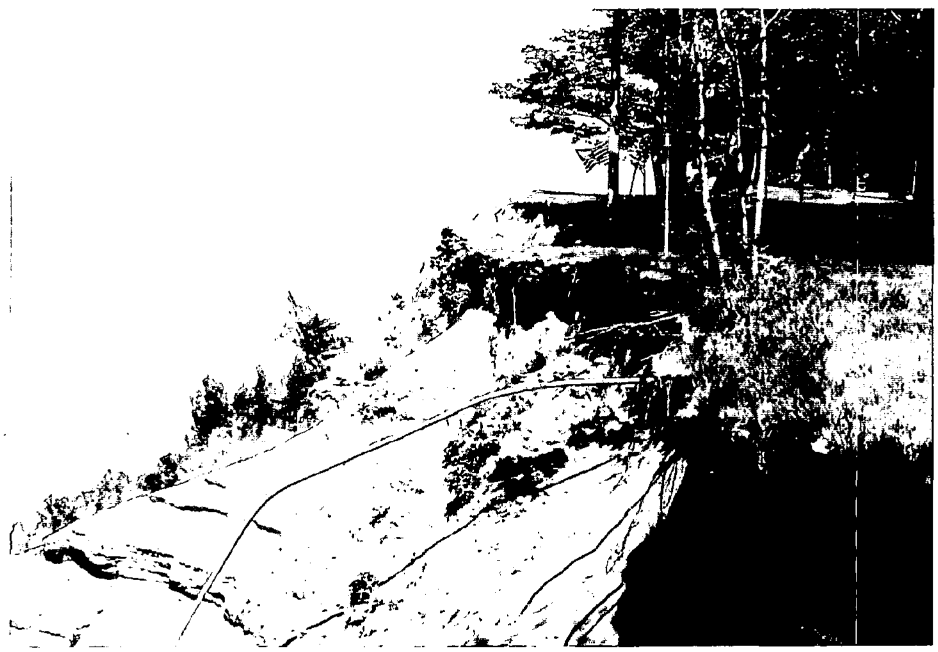
A view east from control point 48.0. Interbedded shales and siltstones. Bluff is thirty feet high and highly resistant to erosion. Recession is these bluffs is slow. Usually, no beach forms at the base of the bluff because of the lack of beach forming materials, the slow rate of erosion, and the steepness of the slope. Sometimes the till layer on top is eroded back leaving the flat bedrock surface exposed. In this case, the till layer is undergoing only moderate erosion although vegetation along the crest is being undermined.

Photo # 2

This is a view from just offshore of control point number 47.0. The slight indentation in the bluff face to the right in the photograph is sufficient to permit the formation of a pocket beach. Recession rates are sufficient to prohibit vegetation from taking hold in the till layer above the bedrock. These bluffs are usually steeper than non-cohesive bluffs because of the resistance of the bedrock layers to erosion.

Photo # 3

This is a steeply sloping bluff viewed from just offshore of control point number 7.0. The bluff face is linear because the till layers are retreating along a parallel plane. If the lower layer were less resistant to erosion the bluff would be far steeper. If the upper layer were more erodible, the slope angle would be steeper in the upper slope, less steep in the lower slope producing a compound slop angle. The large rocks are eroding out of the lower till layers.



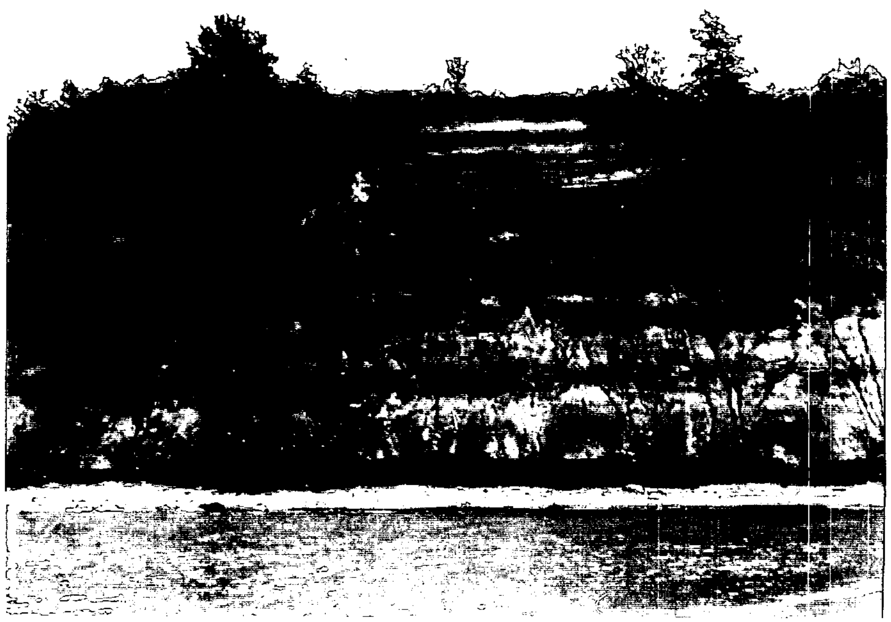


Photo # 4

A view east from control point number 13.0. This is a complex, high bluff prone to rapid recession. Most of the recession in this reach extending from Elk Creek to Crooked Creek is in the form of large slump blocks. The sandy layer on top of the till loses shear strength as the tills are eroded by sheet and flow wasting. Thirty feet of recession has been measured in these bluffs over a recent four year time span. These sands are reminders of post glacial lake levels.

Photo # 5

A view easterly from control point number 16.5. The sandy layers here reach thicknesses of twenty feet or more. Loss of shear strength due to drying and oversteepening take an annual toll exceeding the .8 ft/yr long term average recession rates. Undercutting of the sod layer is always an indication of rapid annual ly high recession rates.

Photo # 6

This is a view from just offshore of control point number 4.0. Rapid recession in these till/lacustrine bluffs is evident by the steepness of the slope angle, the linear face of the bluff, and the absence of vegetation.

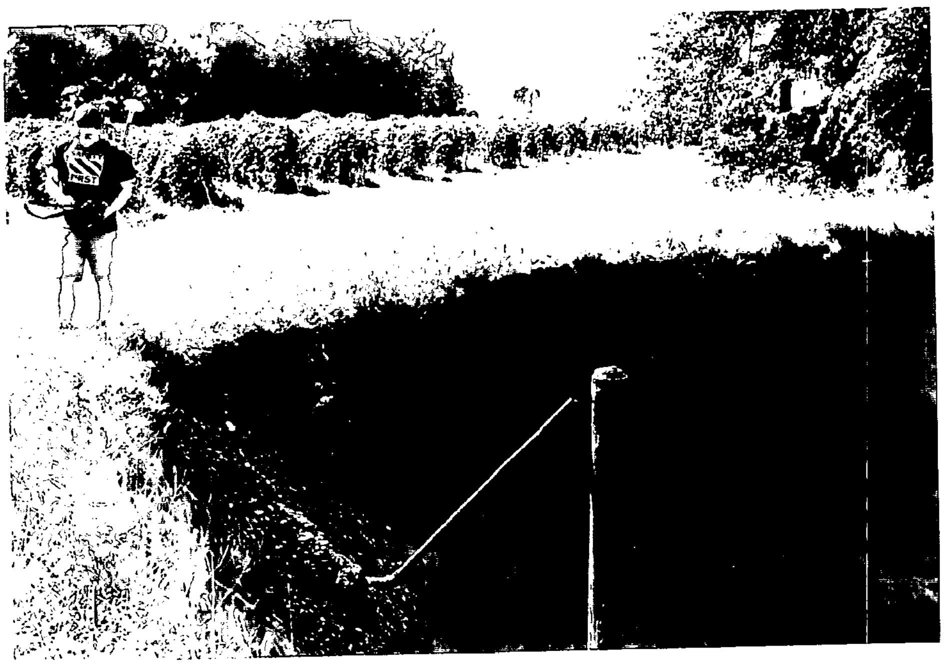


Photo # 7

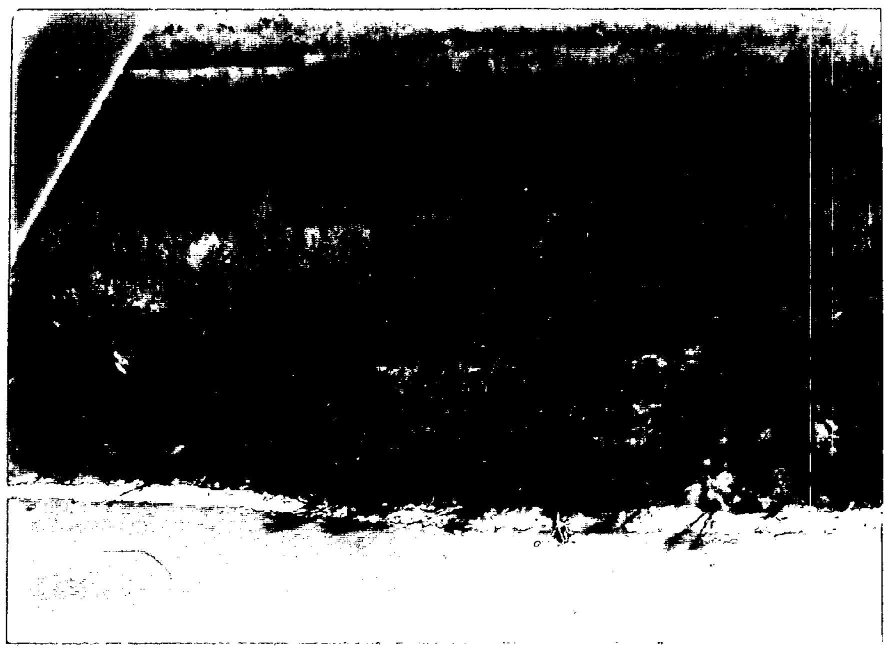
These arcuate forms are produced in otherwise linear bluffs usually in the presence of a highly localized causal factor. These forms are found where drain pipes from home construction are laid to the bluff edge. They can also be produced by groundwater piping at the base of the layer. Large amounts of material are associated with these events which can be sudden and dramatic. After the initial event these forms tend to stabilize for long periods of time.

Photo # 8

An excellent example of the above. This is a view of the control point at site 59.0. A gas well and associated pipelines has caused the loss of a considerable amount of bluff in a highly localized event.

Photo # 9

An aerial view of the bluffs between Sixteen Mile Creek and Twenty Mile Creek. There is a perceived relationship between bluff height and erosion with recession being directly proportional to bluff height. The use of GIS for data mined from ongoing studies can verify this hypothesis. Recession in these bluffs is exacerbated by the thick later of post-glacial beach sands exposed at the top.



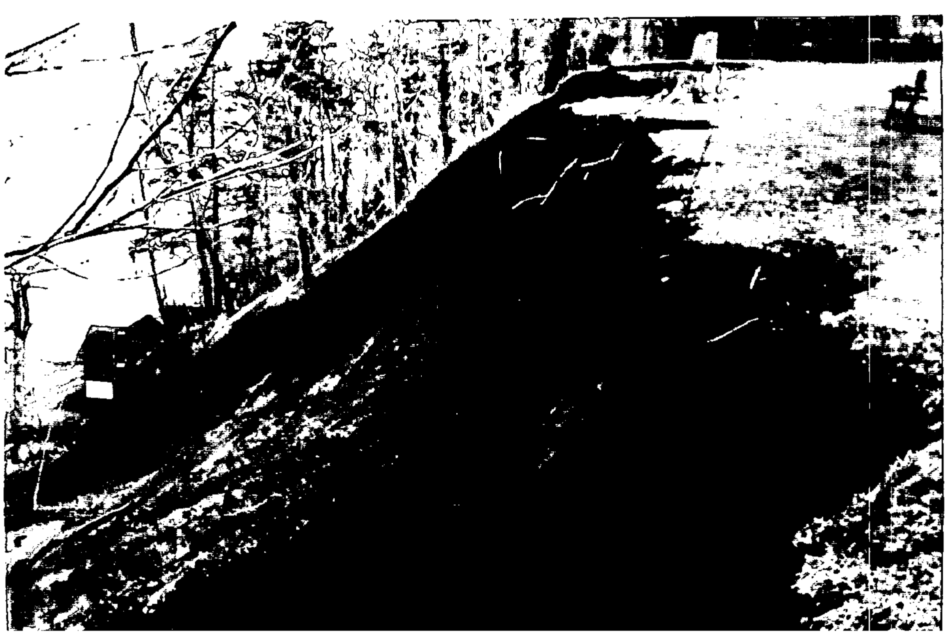


Photo # 10

This is a view west at control point number 20.5. This is a classic slump block produced in lacustrine sands. Weight of vegetation on top and undercutting below combine to produce loss of shear strength along planes of shear stress in these materials. Some blocks can be forty or feet wide with a longshore length of one hundred or more feet. Sometimes vegetation on the block will survive upright until the block reaches the base of the bluff and is destroyed by wave action. The bluffs at Lake Erie Community Park are very prone to this phenomena.

Photo # 11

This is an aerial view of control point number 9.0. This reach is also very prone to slumping. Some of the control points along this reach have lost as much as twenty feet over the last fifteen years, sometimes as the result of a single slumping event.

Photo # 12

A view east from control point number 33.5. This is a high till bluff experiencing very rapid recession due to a combination of loss of protective beaches, urban runoff, and poor land management choices at beach level and at the bluff crest

Section 3.0 Pennsylvania Efforts in Bluff Recession Monitoring

Introduction:

Formal bluff recession monitoring of Pennsylvania's coastal bluffs along Lake Erie began in 1974 very soon after a coastal zone management program was established in Pennsylvania. The Commonwealth contracted the Great Lakes Research Institute in Erie, Pennsylvania to conduct an inventory of shore hazards including coastal flooding and bluff recession. One goal was to obtain information on the relative rates of recession along the open water shoreline. With a known rate of recession, a management program could address planning and regulatory needs for existing and future development.

Until that time, all information about bluff recession rates was based on anecdotal information collected from property owners. This type of information, while useful in understanding recession in general terms, is inadequate for determining recession rates. A comprehensive way of examining recession over long periods of time for the entire shoreline reach was needed.

In 1974 there were two basic ways of establishing recession rates- by remote sensing (photogrammetry), and by direct measurement. Since recession rates are based on temporal changes, there was no way to establish rates by direct measurement. Unless there exists a baseline monitoring system based on ground reference points, the method can not be used. None existed in 1994 limiting the Commonwealth efforts to remotely sensed data. By 1982, it was determined that control points should be established along the shoreline for the purpose of establishing a direct measurement base line. Several alternatives for establishing these points were discussed. A system of control points spaced one kilometer apart along the shoreline was chosen over randomly selected sites. The control points were established in 1982 and measurements were taken. The plan was to revisit these sites in five years, remeasure them, and establish a recession rate for the five year period.

The sites were revisited in 1986 and 1987. In addition to remeasuring the established control points a decision was made to add control points by establishing control points equidistant between the existing control points providing sampling based on .5 kilometer spacing. This closer spacing and the addition of more sampling stations would provide a clearer picture of recession rates over time.

The control points were revisited in 1989 by DER surveyors. While some data and field notes are available, to our knowledge there exists no report on these activities. The data collected by this effort is examined in the overall recession rate analysis (Section 6.0)

The control points were revisited in 1994 with the intent of remeasuring all those remaining and, additionally, to fix the position of each one with existing Global Positioning System (GPS) technology. Also, it was to be determined if this technology could be useful in monitoring recession rates and to provide a more efficient way to collect recession related data.

In addition to these efforts, research and field projects conducted by the Department of Geosciences, Edinboro University of Pennsylvania from time to time provides additional information on randomly selected sites along the shoreline. This information, while accurate in a site specific sense, is in no way as comprehensive as formal Commonwealth efforts to monitor its existing control points over time.

3.1 Photogrammetric Analysis: 1974/75

This work was done coincident with an investigation of the Lake Erie shoreline by DER and its consultant the Great Lakes Research Institute. The data produced was reported in Knuth and Crowe, 1975.

Aerial photography of the Lake Erie shoreline for 1938, 1950, 1959, 1969, 1974 , and 1975 provided a means of determining a historical recession rate. The nominal scale of imagery for all years except 1974 and 1975 was 1:20 000. The nominal scale of the 1974 imagery was 1:14 000 and the nominal scale for the 1975 imagery was 1:24 000.

Scale comparisons were made using 7 1/2 minute United States Geological Survey quadrangle maps as the principal control. Distances on the aerial photographs were measured using a Microline Super Gage which measures in calibrations of 1/1000ths inches. The technique is detailed in the referenced report.

Measurements were made at eighty-nine locations along the shoreline east and west of Presque Isle peninsula. Points were established using the 1939, 1959, and 1974/75 aerial photographs. The problems encountered using this methodology are:

- The imagery was produced by the Department of Agriculture and was intended for use in agricultural planning. These photographs carry a nominal scale of 1:20 000, a small scale for attempting precision measurement.
- The photos are not orthophotos; errors in measurements made away from the center of the image can occur if care is not taken in scale correction.
- The flights were generally made in late spring or summer. Tree canopies make it difficult to see the actual bluff line.
- Magnification of the image cannot exceed 10X without losing the image in the emulsion base.
- Landmarks used for establishing a base line for measurement had to be common for all years 1938 through 1974. Much of the shoreline was undeveloped in 1938 and common landmarks were few.

There were other problems but the above had to be overcome if the methodology was to provide accurate recession rates. The basic methodology consisted of the following:

A scale conversion program was used to scale correct the aerial photograph along each transect by using common points on topographic maps (scale 1:24 000) as a constant. The distance from common base lines to the bluff edge was measured using a precision magnifier with an imbedded scale calibrated in 1000ths of an inch. Eighty-nine transects were used over the combined reaches east and west of Presque Isle for a density of one point per .67km.

Recession rates for the 37 year historical record varied from .125 ft. per yr. to 4.391 ft. per yr. The average rate of recession of all transects measured was 1.075 ft. per yr. With anomalies removed the average rate of recession over eighty points was .874 ft. per yr. (See Section 6.0)

3.2. Miscellaneous Studies: 1975-1977

During the summer of 1975 students from Edinboro University of Pennsylvania working under Paul Knuth established twenty-three control points along the Lake Erie shoreline in Pennsylvania. The points were established using landmarks that could be easily found for future measurement. Sometimes a utility pole was used, sometimes the corner of a house. Basically it was a "metes and bounds" type exercise designed to introduce students to planning and executing a field problem. The sites were revisited from time to time to take pictures and to record the amount of recessional loss.

The points were randomly selected based on ease of access, type of bluff and evidence of recent rapid recession. These points were revisited in 1982 and 1983 as part of a geotechnical study conducted by DER. Five of the initial sites were lost or not measured. These points were used to help verify the photogrammetric analysis and represented the first "on-the-ground" efforts. Recession rates varied from 0.0 ft. per yr. of loss over the eight year period to 2.380 ft. per yr. for an average rate of recession of .827 ft. per year. (Compare to the average recession rate for the 1975 photo reconnaissance of .874 ft per yr. and the average recession rate reported in 1995 from measurement of the recessional control points established in 1982 and 1986 of .8965 ft. per yr.)

3.3 DER Recession Rate Study: 1982

A study was conducted for DER in 1982 and 1983 by the Lake Erie Institute for Marine Science and their consultant, Coastal Research Associates, Inc. The results of the study were reported in Knuth, 1983.

The purpose of the report was to gather information about selected sites along the shoreline that would be useful in interpreting bluff recession phenomena and bluff physiography for shore property owners of Erie County. Data was collected relative to stratigraphy, bluff face geometry, bluff crest line geometry, and physiography. In addition, control points were established on a grid of one kilometer spacing beginning at the Ohio-Pennsylvania border to the proximal end of Presque Isle peninsula and from International Paper Company east of Erie to the Pennsylvania-New York border. The control points were numbered 1-33 and 44 through 73 respectively.

The fixed grid survey was chosen over the random survey and the problem-oriented survey because the intent was to derive information pertaining to bluff characteristics irrespective of stability. Recession rate analysis was secondary to the primary goal of understanding the geotechnical attributes of coastal bluffs.

A one kilometer grid was selected as an interval that could best provide extrapolation of information between points. A basic disadvantage of the fixed grid is that an exact spacing may cause the point to be fixed on a section of shoreline that lacks a bluff (stream mouths, for example), property owner resistance to on-site field examinations, or access problems. Some latitude was granted in the spacing of the control points to overcome these and other problems. Therefore, the spacing, when mapped, produces a grid that approximates a respect for the one kilometer spacing but is not exact.

The geotechnical study was designed to gather information about aspects relating to bluff geometry and morphology. The following were measured or described: bluff height, bluff angle, bluff shape, shape of the crest, stratigraphy, beach profiles, and offshore bathymetry. The distance to the bluff along a line normal from a fixed point at least fifty feet landward to the bluff edge was recorded. The fixed point became a control point with a location described in such a way so as to located for subsequent survey. (See Section 4.0)

These control points were to become central to a program of measuring future bluff recession.

3.4 DEP Recession Rate Study: 1986/87

In 1986 DER made a decision to follow up on the 1982 geotechnical study. The intent was to provide an early verification of recession rates established by the photogrammetric method used in 1975. The information was to be used to reinforce regulations relative to structural set-back requirements established by the Bluff Recession and Set Back Act. Specifically required was 1) a recession rate determined by valid on-site measurement and 2) the establishment of additional control points to provide information for bluffs falling between the original one kilometer grid established in 1982. Extrapolation between points that were only .5 kilometers apart would provide a better regulatory basis than a one kilometer grid.

As a result of the 1986/87 study recession rates for the original points could be determined although the rates would be based on only a four year time period. In addition, the measurements taken on the supplemental points would provide an additional baseline for future studies. The supplemental points were established using the guidelines developed in the original geotechnical study done in 1982. These points were numbered to fall between the original numbers i.e. .5, 1.5, 2.5, so forth.

The study was not designed to provide the geotechnical detail of the original however. As a result, no information pertaining to geometry, morphology, or physiography was recorded. Recession rates established by the study are reported in Section 6.0.

3.5. DER Recession Rate Study: 1988/89

The author knows little of this study with respect to purpose or intent. No report of the study exists. Data is available and field book notations on the 1986 study field books are available. This is the only study of the four described using DER control points that was done independent of the other three with respect to personnel. The 1994 study described below found basic errors in the 1989 study in location and measurements taken from a number of control points. Recession rate analyses using this data may produce some anomalous rates, negative recession rates for example. Since new measurements are available for all control points in the 1994 study the impact on overall recession rates 1982-1994 and 1986 to 1994 is minimal. The measurements provide some chance for developing a trend analysis in recession rates.

3.6. DER Recession Rate Study: 1994

The purpose of this study was twofold. First, the study was to comply with a stipulation that recession rates would be verified every five years. The stipulation falls under the Bluff Recession and Setback Act. Secondly, the study was done to determine if recession rates could be determined using remote sensing and recent technological advances in Global Positioning Systems (GPS) and a Geographic Information Systems (GIS) approach to the problem. Locating and remeasuring DER control points using current practice while simultaneously experimenting with GPS technology would provide a means of evaluating the new technology. GPS and GIS technology as applied to work by DER 1992-1994 is described in Section 3.0.

During the 1994 summer field season a crew relocated as many of the original and supplemental control points as was possible given erosion and development at some sites. (See Section 7.0) The recession rates determined by these measurements are consistent with average recession rates determined by previous studies.

New York and Ohio currently use a combination of photogrammetric, planimetric, and digital processing techniques to determine recession rates. (See Section 4.0). Historical recession ratesin those states are based on charts drawn on surveys by the Army Engineer Corps in the mid 1870s and compared to recent aerial photography. To gain some historical insight on Pennsylvania's recession rates since 1875 and to provide some data similar to that produced by border states, a complete set of these charts was obtained for the Erie County shoreline. A grid of .5 kilometers was superimposed on these charts and measurements to the shoreline were made on transects established from points common to the 1875 chart and orthophotography available for Erie County derived from a mission flown in 1991. While not having the accuracy of the direct measurement method, the information provides historical perspective. The results of the survey were incorporated into the DER GIS data base established for the Erie County coastal zone.

3.7 Summary

DERhas been involved in studies of the Lake Erie Bluffs since 1974. Foresight on the part of managers then and now has provided a twenty year perspective on bluff recession. Pennsylvania has the most comprehensive and accurate data base in the Great Lakes based on field measurements over a twelve year period for its entire Lake Erie reach. Recent recession rate studies have given validity to past efforts and are consistent with those found by independent research.

Available and evolving technology in GPS and GIS will enable the Commonwealth to continue to provide shore owners and managers with an accurate accounting of recession phenomena based on past, present and future efforts.

Section 4.0 Techniques for Monitoring Bluff Retreat and Calculating Bluff Recession Rates

4.1. Inventory of Current Practice: Great Lakes

The following is a summary of techniques employed in the Great Lakes by State and Federal agencies to determine rates of bluff recession. The information presented in this section is derived primarily from two sources. The first is a report prepared for DER in 1994 which examines new techniques for measuring, calculating, and monitoring bluff recession on the Lake Erie shoreline in Erie County, Pennsylvania (Knuth and Lindenberg, 1994). The second is a report prepared for the U.S. Army Corps of Engineers, Waterways Experiment Station which examines United States Great Lakes Shoreline Recession Rate Data (Stewart, 1994).

The following methodologies are currently being used by land use planners and researchers in the Great Lakes Basin to acquire, catalog, analyze, and display recession rate data. These methodologies display the variability influenced by length of reach, availability of resources, degree of developmental pressure, and regional mandate. Various methodologies may:

- Acquire recession rate data for random points from a survey of property owners. The anecdotal responses, e.g. "we lost twenty-five feet of beach since we bought the property ten years ago" are reviewed and the long term average recession rate for that reach is derived.

- Acquire recession data by comparing maps and aerial photographs with sufficient historical spread to provide long term averages. Data may be derived by tracing and projecting subsequent years on a historical or current base map, digitizing points and connecting the points to produce a constant line, comparing lines by measuring distance differences between points on the lines with correction based on points common to each historical map or photograph and the bluff edge using computer digitized information or by precision measurement.

- Use direct measurements from surveyed monuments positioned and located for subsequent measurement to derive long term recession rate information.

New technologies will not significantly change the latter two methodologies but will make monitoring more efficient, more accurate, or both. (Improving efficiency may be at a cost of reduced accuracy.)

For each Great Lakes State a summary is provided of scope of study and technique(s) employed to derive recession rates.

Minnesota (Lake Superior)

Until 1994, Minnesota relied only on feedback from property owners to compute long term recession rates. In 1994 a study was conducted using aerial photographs. Available were photographs from the 1930s, 1975 and 1988/89. Direct measurement of the photographs over the period of record produced annual recession rates in the order of .05 m/yr to .33 m/yr (2 in/yr to 13 in/yr).

Wisconsin Lake Superior)

A study was conducted in 1973 for the western arm of Lake Superior. Bluff heights were measured in the field and combined with measurements from maps and aerial photographs to produce a volume of eroded material. Maps dated 1852 were compared with aerial photography available from the United States Department of Agriculture dated 1966. (Note: The methodology used for this study provided the model for the photogrammetric study contracted by DER in 1974/75.)

In the mid to late 70's the Wisconsin Coastal Zone Management Program initiated an inventory along the Lake Michigan and Lake Superior shoreline that included collecting data on shore erosion. The methodology used for determining recession rates amounted to measuring from U.S. Public Land Survey maps and aerial photographs taken over a ten-fifteen year period. Measurements were made by plotting shoreline positions from the older photograph onto the most recent photograph and measuring the amount of recession to the nearest .001 centimeter. Recession rates of <0.3 m/yr to >0.61 m/yr (12 in/yr to 24 in/yr) were reported.

Wisconsin (Lake Michigan)

See above, also:

Two studies were conducted by W.R Buckler from 1975-1988. The first study was conducted for a reach of Lake Michigan shoreline from Kenosha County to Door County. The methodology consisted of using U.S. Government General Land Office (GLO)surveys and by direct measurement. Distances were determined by measuring along survey lines (true bearings along section lines) on the maps dated 1833 to 1836. In 1976 and 1977 resurveys were conducted by making measurements along the bearing of the section lines using measuring tape and standard surveying procedures.

The second study, conducted in 1981, compared bluff crest positions on 1941, 1969, and 1975 photography. Measurements were made using standard methods. This study was done for Kenosha County only.

To obtain information for a bluff setback ordinance, a study was conducted for Manitowoc County. A forty year recession rate was calculated using aerial photographs dated 1938 and 1975. A one hundred year recession rate was calculated using
GLO maps and topographic maps dated 1953 and 1978.

A recession rate for Milwaukee County was produced by remeasuring from section intersects to the bluff crest. Measurements were made from 1836, 1874, and 1944 maps.

A study conducted by the Wisconsin Sea Grant Program for Racine County used topographic maps prepared from aerial surveys dated 1968-1971 and maps compiled from aerial photography dated 1976. Measurements along transects sixty-150 meters apart produced recession rates for the period.

Stewart (1994) lists a number of other site specific studies for the Lake Michigan shoreline. All were done using techniques described above and offer no new insights in measuring or calculating bluff recession.

Wisconsin Sea Grant has developed an extensive bibliography of work incorporating GIS into coastal zone management efforts.

Michigan

Michigan has the longest Great Lakes shoreline of any Great Lakes state. Traditionally, Michigan has developed recession rate data for only those areas for which there is a demonstrated need. For example, state parks, developed areas, developing areas, and special interest areas are mapped. The Michigan Department of Natural Resources is constantly updating the information base as need and resources allow.

The methodology is well established and has not changed appreciably over the past several years. Historical data is derived from aerial photography. Lines are traced using stereo plotters. Shore normal lines are drawn every five hundred feet and the bluffline transect line intercept digitized. It is assumed that recession rates are derived from simple PC programs and graphics software develop the plots. When needed, lines are established between the five hundred foot intervals.

Michigan will be developing a GIS for this data. The choice of the Michigan DNR for all agency use is INTERGRAPH which requires a work station and mainframe capabilities. They already have a workstation in the office and the INTERGRAPH GIS is coming. They are already using something called a Resource Information System.

The Michigan Department of Natural Resources has developed recession rate data for most of the Lake Michigan shoreline. This information was created using historic aerial photographs with recent aerial photography. Direct measurement of the photos developed a distance difference for various years and a recession rate resulting from simple computation.

Some county specific studies have been conducted, e.g. Berrien County , that used a combination of property owner questionnaire, eye witness accounts and air photo analysis. Some of the owners had measured recession for their property and would be able to provide some validity to these studies.

Some academic studies were conducted between 1975 and 1988 that used GLO surveys. Distances on 1838 and 1855 GLO maps were compared with ground measurements on site along section lines, provided data on fifty-six points between Berrien County and Leelanau County.

Studies dating back to the early 1970's provide addition information for Michigan's data base but these studies provide no additional insights into new methodologies.

Michigan (Lake Huron)

Recession studies of the Huron shore are more limited than those done by Michigan for Lake Michigan shores (see above). However, many counties have been surveyed using historic aerial photographs and comparing measurements made on more recent aerial photography. More recent surveys have incorporated the use of larger scale photography with some field reconnaissance to produce more reliable data. The information is used here, as well as on Lake Michigan, for administering structural setback ordinances.

Lake Erie and Lake Ontario

Illinois

Only one major study is found, that being reported in 1992 on bluff retreat measured between 1872 and 1987 from Wilmette to Waukegan, Illinois. The methodology combines the use of historic maps and aerial photographs. Although there is the usual measurement error (up the five meters) in the use of the historic maps, the long term (one hundred years) provides usable data.

The Illinois Geological Survey has been monitoring forty-eight profiles in two locations. Measurements taken on these profiles annually between 1988 and 1991 have provided some recession rate information. Future monitoring of these sites by direct measurement or by other means should provide reliable recession rates.

The USGS has completed a monument based study at an Illinois state park. This is a very site specific study of shoreline retreat. The monitoring system works onshore and offshore (constructs a profile). It can literally "watch" a storm. A GIS can produce maps before, during, and after an event. They have measured a single event loss of eleven feet. The study is discussed in two publications (Steaud and Jipson, 1992). This information could be useful to DER's efforts in developing a GIS for monitoring Presque Isle beach erosion.

The State of Illinois is not currently participating in the Coastal Zone Management Program. However, in the 70's they produced recession rate information that was based on a one hundred year recession line. Some of the work producing the recession rate was monument based.

Some work has been completed using aerial imagery at scales of rf 1:2 400, rf 1:3 600, and rf 1:4 800 derived from enlarging 9" x 9" contact prints. Stereoscopes were used to transfer the data and the information was digitized and input to a GIS.

Indiana

Three studies have been conducted by the Great Lakes Coastal Research Laboratory between 1981 and 1988. Maps were produced from aerial photographs with verification at specific locations provided by beach survey data. The combination of the two gives validity to measurements taken on successive maps. Eighty-seven locations were selected to coordinate with established beach survey lines or easily recognized landmarks. The methodology is reliable but the rates of recession will be skewed by the non-randomness of point selection.

New York

The State of New York has developed recession rate information for Lakes Ontario and Erie. In addition, their marine district (Long Island, etc.) is developing shoreline change information in conjunction with sea level rise studies. Recession rate information is developed for shorelines where the expected recession rate is expected to exceed one foot per year.

The Lake Erie reach does not exceed this rate except in Chautauqua County. Most of Lake Ontario exceeds this rate (up to five feet per year) and is mapped.

Lake Survey charts produced by the Corps of Engineers in 1875 and 1876 are used as the primary historical reference. Aerial photographs (1989) were used to provide the long term recession rate. The bluff lines were transferred using stereo plotters and a zoom transfer scope. Measurements were made between the lines shore normal every one hundred meters. A long term recession line (twenty-five feet) was drawn using a five point moving average of data obtained for each one hundred meter interval.

This recession line is mapped at a scale of 1" = 200' (rf 1:2 400) and used by managers and property owners at the local level.

New York bluff setback legislation provides for a zone between the bluff edge and landward twenty-five feet to be considered as part of the bluff as well as an additional forty foot structural setback beyond the twenty-five foot line.

New York includes the bluff face within the protected bluff zone. Pennsylvania should amend the Bluff Recession and Setback Act to consider the beach and the bluff face.

New York would like to use a GIS for recession analysis, storage, and display. The system that Department of Environmental Conservation (DEC) has developed is not able to accurately display the linear offsets of recession with respect to shoreline length (the scale problem). DEC has hired a consultant in the marine district to develop a GIS for marine applications. It is not known if that technology is transferrable to the Lakes.

Ohio

Ohio has based its long term recession rate averages on historical information including the 1875 Lake Survey charts, 1973 aerial photography, and 1990 aerial photography enlarged to conform with the Lake Survey Charts. A stereo plotter was used to trace lines onto a single format. Shore normal lines were developed on the photo base and photogrammetric controls were established. Lines were digitized one hundred feet apart.

For each line the bluff's edge in 1875, the bluff's edge in 1973, the bluff's edge in 1990, and the bluff toe in 1990 were digitized. The digitized information is plotted on a drum plotter. A simple program was written to determine the average recession based on the digitized points and an erosion hazard (setback) line was plotted. The resulting plots can be xeroxed and distributed to municipalities and private property owners.

The one-hundred foot interval was dictated by property owner complaints that recession information was being developed that didn't take into account their special case, thus the one hundred foot interval. The Ohio Department of Environmental Conservation (DEC) believes that the one hundred foot interval is excessive and has a statistical study to support this.

At this time Ohio does not have a GIS system. Data is compiled and input to a PC spread sheet for data manipulation. Graphing software enables the data to be plotted. There is no supporting geographic base information on the maps. DEC has purchased ARC/INFO and are well into making a conversion to this GIS.

4.2 Synopsis of Techniques Applied for Current Study

4.2.1. Global Positioning Systems

The Global Positioning System for Geographic Information Systems provides a means of establishing location (latitude and longitude or state plane coordinates) and altitude for a point or for a series of points producing line data. Area applications are also indicated e.g. wetland delineation, soil analysis, so forth. GPS receivers are made for GIS applications and their effectiveness in the field produces solutions to problems long faced in locating control points accurately.

GPS systems are accurate to one hundred meters uncorrected. GPS signals are corrupted deliberately by the United States Air Force. This policy, known as Selective Availability (SA) is imposed for security reasons. Accuracy can be enhanced by using a second receiver called a base receiver. The base receiver is capable of correcting the signal errors (differential GPS). All GPS/GIS receivers have differential GPS capability. The easiest way to do this is to set up a receiver to collect and store data at a known position. (The base receiver must always be running at the same time data is being collected in the field.) This data is used by software packages to post process field data. The accuracies expected range from a few decimeters to 1 m.

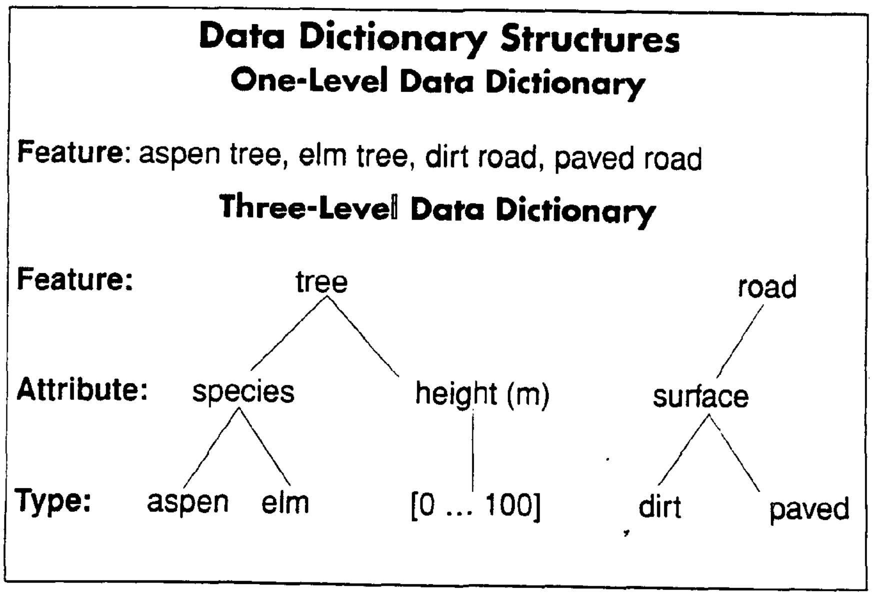
Another way to overcome the SA error would be to carry a radio receiver into the field that monitors corrections transmitted by a differential GPS service. This can produce real time correction that can be used in the field to locate control points.

There are currently twenty-four GPS satellites in operation. Only four are needed to derive location and altitude. The more channels a receiver has, the better, but there are usually only six satellites available. A GPS receiver with six to eight channels is sufficient to take accurate measurements. One limitation on accuracy is the need to collect data on a fixed point for several minutes to allow for differential accuracy to the sub meter level.

GPS/GIS receivers store data that can be transferred to the GIS. A data dictionary can be developed to collect a wide range of data on the site providing an efficient and accurate way of obtaining equivalent data for all sites. When this stored data is downloaded via IBM compatible hardware devices and software that comes with the GPS the data is incorporated into the GIS, in our case ARC/INFO. The transfer is done through the serial port. This is as easy as connecting the receiver to the computer serial port. The recommended GPS receiver is the data logger type typical for backpack models like the Trimble Pathfinder.

It is important to construct a well thought out data dictionary for use in the field. The dictionary used for the 1994 field season is incorporated into the DER GIS data base and can be viewed via ARC/INFO or ARCVIEW.

A typical data dictionary is constructed similar to the one below to provide at least three levels of information for a particular point, line, or area.



4.2.2. Geographic Information Systems (GIS)

The tasks outlined above (data processing and product generation) are largely addressed by the same system. The quality and continuity of the coastal data obtained should be matched to a commensurate data processing system. For anything except the simplest tabulation and analysis of data, a geographic information system (GIS) is required. A GIS is a combination of computer hardware, software, digital data and procedures that is used to manage information having a common geographic reference. In today's market the GIS is also the engine for product generation. The exact possibilities are constrained by the computer system.

The capabilities for data input, data management, manipulation, analysis and product generation of the coastal environment will be determined by the GIS which is used. Although the wide variety of hardware and software available could result in a wide-ranging discussion, it may be quickly focused by the fact that there are a limited number of systems which enjoy wide utilization in the field and that there is a particular infrastructure already in development at DER.

The most established products in use today for GIS are systems produced by Intergraph and ESRI (Environmental Systems Research Institute, Inc). ARC/INFO is the name of software for GIS produced by ESRI. Software developed by these firms will operate on IBM (and compatible) personal computers and on computer workstations (e.g. those manufactured by Sun Micro Systems or Digital Equipment Corporation (DEC)).

The capabilities of modern GIS are too vast to detail here, but an idea of the utility may be provided by some examples of how a GIS, like ARC/INFO, might be used. If data at points for the position of a coastal bluff is obtained, the system is able to construct a line through the points and display it. If such data over time is available the lines can be compared for the amount of area which has been lost due to erosion. If a digital orthophoto is available as a visual backdrop for the screen one can see the bluff position in relation to other features. A database can be established which could be accessed by pointing to a location on the computer screen and clicking the mouse button. For example a house could be tagged with data about ownership which is accessible in this way. As a final example buffers can be determined by the system and displayed at any chosen distance from the bluffline.

Product generation, the third task, is the output of the GIS. It generally consists of reports, tables and maps. In the examples above one can visualize the type of output that might be useful. The information can be seen immediately on the computer screen. A printer can supply tabulations. For example, bluff recession at the measured points could be printed as a table. Maps can be printed or plotted, as well as seen, on the screen. The devices chosen for this purpose affect the flexibility in this area. Typical concerns are the largest map which can be drawn and the availability of color. In addition, slides and photos may be scanned and included in the database. These can then be accessed by pointing to a position on a map on the screen.

A GIS is composed of computer hardware and software. The software consists of data and programs (like ARC/INFO). The hardware is the computer and peripheral equipment. A PC, or personal computer, is sometimes termed a microcomputer and is found on many office desks. Computers with more powerful processing ability are called workstations. Although more powerful than PC's, many workstations are no larger than a common PC.

Other hardware associated with the computer include the monitor, memory and storage devices. The monitor is the screen for the display. Although monitors are a common item, large monitors are necessary for GIS use to show maps. Memory (often described as RAM or random access memory) is used by the computer to store information in a quickly accessible location. This storage is erased when the power to the computer is shut off. Permanent storage for the computer involves tapes and disks of various types.

The most common storage device is often referred to as a hard disk. The capacity of this disk determines how much data the computer can access relatively quickly, although not as quickly as RAM. This storage remains even after power to the computer is shut off. Data can also be stored on tape (generally a cassette) or on a CD-ROM (compact disk). Some times each of these storage devices may be called a drive (e.g. hard drive, tape drive or CD-ROM drive). Tapes and CD-ROMs are relatively inexpensive for a large amount of capacity when compared with a hard disk. They transfer data to or from the computer too slowly for many uses, however. For this reason, frequently used data needs to be on a hard disk.

A GIS typically requires the storage of large amounts of data. The need is generally satisfied with some combination of a hard disk, tape and CD-ROM. The combination should balance cost with storage capacity and access speed.

Data from maps needs to be converted into a form usable by the computer. A digitizer resembles a drawing board but can electronically detect the position of a line following device that looks like the common computer "mouse." The position is then stored in the computer.

GIS data may be obtained from remote sensing which includes data acquired by satellites and from aerial photography. Aerial photos that have been processed to correct for their distortions are called orthophotos. They can be changed to a form readable by a computer through the use of a scanner. This produces a product called a digital orthophoto. Scanners are ordinarily owned by businesses which provide this service.

The results of a GIS can be in the form of reports, tables and maps. Many options exist for this purpose. Text can be output on computer printers of the type found in any office. Maps require more specialized devices. Color and black-and-white printers and plotters can be used.

Plotters and printers vary widely in price depending on their capabilities and size. Maps are often desired in large sizes. All of these devices increase in cost with increases in printing or plotting size. Color is an attribute which also increases the cost of the device. Maps may be printed with pen plotters which move a pen across the paper surface. An alternative technology which finds use in color mapping is called an electrostatic plotter.

Section 5.0 Field Reconnaissance

5.1. Methodology

This section is designed to assist in the planning and execution of a successful reconnaissance of all control points. The section provides a list of materials needed in the field as well as procedures for locating and collecting meaningful data. It is presumed that GPS technology will advance greatly in the next few years. The description of the GPS technology used in 1994 serves to provide an explanation of how the data was collected. Emerging technology will only make data collection easier and, positioning more accurate. It should be remembered however that the GPS technology is most useful in locational work. Its use in direct measurement of distances point to point will not substitute for the accuracy of direct measurement from a fixed point for some time.

Organization:

The following materials should be organized prior to field work and carried along as needed for specific sites. The list is divided into those things that are useful but not necessary and those things necessary most of the time.

1. Useful Items.

• Road map of Erie County with minor civil divisions and all roads named.
For surveyors unfamiliar with the County, road maps provided by township offices might be more useful since the scale is generally larger.

• Telephone directory (hardly ever used but handy on occasion to verify an address or to call a property owner).

• Topographic maps with the control points located. Mostly redundant but useful for more remote sites when walking point to point. The quadrangles (all 71/2 minute sheets) required are East Springfield, Fairview, Fairview SW, Swanville, Erie North, Harborcreek, and Northeast.

2. Necessary Items:

• Printout of control point data listing property owner, address, and recessional information to present

- Printout of control point data list location by state plane coordinate system (necessary for GPS methodology)
- Printout of control point data related to attributes collected by data dictionary during 1994.
- Printouts of GIS overlays of control points by reach (Scale to be determined by surveyor)

Note: The above may be obtained directly from GIS overlays or from GIS data base that provides this information in tabular form.

- Field notebooks used in 1986, 1989, and 1994 field work

(These notebooks contain copies of site photographs, directions, trilateration information, information about the control point including character of marker, date of first measurement, and a record of previous field measurements. The notebooks contain corrections made by subsequent visits and are invaluable for locating control points.

- Field Book. The field book should be prepared before hand to provide a means of efficiently recording required information used to back up the GPS record file. The best way to do this is make up sheets, have them punched and ring bound for use in the field. The sheets should have spaces to record the following:

Control Point Number
Date
Time
GPS File Created
Distance
35mm Photo Roll Number and Frame Number
Panoramic Photo Roll Number and Frame Number
Field Crew
GPS Information: PDOP on Control Point Location, Number of Points
Collected; PDOP on Bluff Point Location, Number of Points Collected
Notes/Remarks

- Photographs of the site from previous visits. Kept in a card file, these photos, some dating back to 1982, provide useful visual clues for establishing provenance on site location. They are usually necessary when the control point is established where there are no significant fixed landmarks such as a house or garage or, where the site has undergone some change. By looking for a specific tree branching pattern or the lay of the ground sufficient provenance can be established and landmarks located.

- Two cloth engineer tapes (graduated 10ths of feet) on an easy wind reel, 150 foot length
- Brunton Compass (pocket transit)
- Tripod for Brunton Compass
- Plumb Bob
- Three Surveyor Pins
- Metal Detector
- Small Trenching Shovel
- Machete in Scabbard (for remote, brambly sites)
- Abney Level or similar
- 35 mm camera
- Color Print Film (ASA400)
- Panoramic Camera (Kodak disposable)
- Rucksack
- GPS (Trimble Pathfinder or Similar)
- GPS Almanac (For selected field days)
- A copy of this report

5.2. Procedures for Locating Control Points

5.2.1. Determining the General Location

Finding the general location is generally easy to moderately difficult. Those points which are established on a developed property are not difficult to locate. Using the county map or township road map to locate the appropriate road or street drive to the given address. For points on properties which are undeveloped location is more difficult. Using the description provided for each point locate the appropriate road or cross roads. Distances from a landmark along the road to the vicinity of the control point are provided in many cases. In some situations there are multiple consecutive control points located far from direct individual access. Control Points 8.5 to 13.5 are examples. In such cases walking from point to point provides the easiest way to generally locate the point.

5.2.2. Finding the Marker

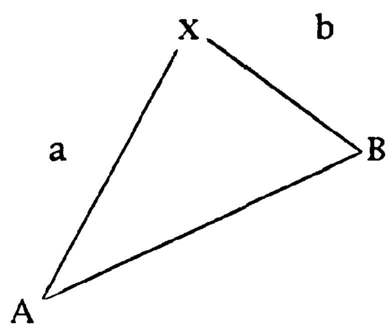
Markers consist of the following:

1. A short length of three quarter inch rebar cut to a length of twelve inches driven below the surface of the ground one to two inches. These pins were used in 1982 to establish the original control points whole numbers 1-73.

2. A landscape nail driven below the ground surface 1 to 2 inches. These pins were used in 1986 to establish supplemental control points numbered .5 , 1.5, 2.5, etc.

3. A readily available and identifiable permanent marker such as a utility pole (which is always numbered with some identification plate), a hydrant or something like that. When these are used, it is indicated in the site information.

If the marker is located on a developed property it is found by trilateration using easily located landmarks. For example, Control Point Number 25 is found by:



A= the westernmost corner of the structure
B= the easternmost corner of the structure
a= distance A to the control point
b= distance B to the control point

For trilateration methodology to work, only two measurements are needed. Trilateration works best when the angle produced between the two coordinate bearings is close to ninety degrees. Three people are required. Hold the "0" end of the tape against each respective landmark, and pull the tapes each to the appropriate distance. The point lies where the measurements of each tape intersect. Set a marker at this intersect. For accuracy, hold the tapes parallel to the ground and drop a plumb bob from the point where the two tapes intersect.

Remember, the bearing is not important for trilateration but may be useful in locating the correct landmark. Use a metal detector to verify the location. The pins contain enough metal to produce a distinct response. Metallic scraps in the ground produce false results. The pin must actually be found by probing with a pin or with the shovel. A flat shovel worked into the sod at an angle will usually produce good results, and the sod can be restored without damage to someone's lawn.

If the marker is above ground, e.g. a utility pole, locate the landmark with the description provided. Verify the marker by checking the ID # on the pole or by using visual clues from the site photographs.

If the marker is a buried pin on undeveloped property, the difficulty in locating the pin is proportional to the amount of vegetative cover and the remoteness of the site. Traditionally, locating such points was successful based on familiarity with the site, visual clues (photographic evidence, ribbons tied on branches), and sometimes, luck. A description of how this is done follows.

During the 1994 field season, each control point was location was established by GPS. Current methodology using basic equipment permits navigation to a known point to within one hundred meters; not enough for a good determination. Evolving technology sufficient to overcome scrambling by the military will permit navigation to within a few meters of a known location. A modest addition to the hardware used to locate these points will permit co-processing in the field.

By the year, 2000 navigation to a known point will be easily achieved with a modest investment in technology. A discussion of how GPS technology is used to navigate to a known point follows the discussion of traditional methodology.

The task of finding markers in undeveloped areas is appreciated by remembering that the surveyor is attempting to find a buried pin 3/4 inches (Or smaller) in diameter. The pins can be located in forested areas and sometimes with understories full of interesting and varied underbrush. Under these conditions trees and tree patterns all look similar and the possibility of finding the marker seems remote. With a little experience, however the pins can be found by following directions and using visual clues.

It could be like this:

Drive to the nearest access point to the bluff and or the marker. Follow general directions. For example "walk westerly along the bluff where it rises west of Elk Creek to the second ravine intersecting the bluff. The pin is located 50 feet west of the western bank of the ravine." Using photographs and other clues like ribbons tied on branches, locate the marker trees. The trees may be blazed or have a nail driven in about waist height. Once the trees are found use trilateration to find the pin. Verify by using the metal detector and then dig to locate the actual pin. (Before leaving the site, remark the trees with orange ribbon. In many cases control points have been found by first finding a ribbon placed years previously.)

5.3. GPS Methodology

Using the GPS in the field is straight forward but requires planning. The following narrative presumes knowledge of GPS systems including training on the use of advanced systems like the Trimble Pathfinder.

Before going out in the field the survey party must decide on which base station will be used to provide the co-processing data necessary for use with the GPS software to correct readings obtained in the field. (In five years time the need to co-process data may be relieved by the government's deciding to refrain from scrambling the satellite information.) In 1994 we used both the National Fuel Gas data from a receiver at 10th and State Streets in Erie, Pennsylvania and the National Forest Service receiver in Warren, Pennsylvania. The survey party must be sure that one or the other stations is recording satellite information for the time in the field. That information must be transmitted by tape or modem to the host PC.

Using the GPS receiver, the survey party should use the function key on the GPS receiver for obtaining almanac data on satellite positioning for the days in the field. The information may be displayed on a computer screen and printed to a peripheral.
The almanac will provide information on time of day when satellite positions will be ordinated in such a way as to provide poor positioning data (i.e. a high PDOP).

A data dictionary should be constructed for use with the GPS. It may be the same as used in 1994 or modified to gather additional information. The existing data base can be easily updated in the field and corrections made to existing information found to be inaccurate or incomplete.

In 1994, the following attributes were recorded by means of GPS:

Control Point Number
Status Found /Not Found
Bearing
Distance
Date
Time
Control Point Coordinate (State Plane Coordinate N.A. Datum '83)
Slope Angle
Slope Type Complex/ Linear/ Concave/ Convex
Vegetation Type (on slope) None/ Mixed/ Scrub/Shrub/ Trees
Vegetation Condition
Percent Vegetated
Vegetation in Upland Mixed/ Landscaped
Stability
Stratigraphy
Hard Stabilization
Beach Dimension
Beach Sediment Type sand/ sand/shingle/ other
Crest Form (horizontal)
Crest Form (vertical)
Land Use recreational/ undeveloped/ other/ residential

5.3.1. Using the GPS to Find the Control Point

Using the GPS to relocate remote control points, those that are located along undeveloped and heavily wooded bluffs, for example, is a basic matter of understanding rather simple directions that come with any GPS unit. The GPS locations for the current study were derived using a very expensive unit that could record data, store it, and later transfer it to a basic PC driven software package. The accuracy of the unit was tested and found to be correct to the nearest meter after post processing, under optimum conditions. Using the GPS to relocate the precise point to that accuracy is not necessary. Current GPS methodology does not permit navigation to a fixed point with anything greater than an accuracy of fifty meter. unless the surveyor is carrying a receiver capable of real time correction of signals.

A basic GPS unit, now selling for $200-$300 would be adequate to find the general location of the control point even in remote sites. Using the directions on the unit, the coordinates are input and the unit will provide bearing and distance to the control point. It really is that easy. The Trimble Pathfinder used in the original survey is, of course, capable of using the same system of waypoints to relocate a known position.

5.3.2. Procedures for Collecting Data on Control Point Sites

The process of recording the information can begin once the control point is found. At a minimum, distance from the control point to the bluff crest should be measured using traditional means with the engineer's tape. For accuracy, a tripod and pocket transit (Brunton) are mounted over the pin. Use a plumb bob for precise positioning of the center of the transit over the pin. Using the data base for the site, find the appropriate bearing, pin to the bluff edge. These bearings are recorded as magnetic bearings (seven degrees West declination). Using a surveyor's pin to anchor the "0" end of the tape, stretch the tape to the intersect of the bearing line on the bluff crest and record the distance. In the case where recession is active, the bluff crest line is easy to determine and the measurement may be made in tenths of feet gradations. Where recession is slow the precise bluff crest may be harder to determine. The edge may be vegetated and rounded. In this case make an estimate and compare the distance recorded with that recorded previously. If the bluff is that inactive, the distance should be the same, sometimes a bit less, and never greater than previously measured. (There are cases where the distance from the pin to the bluff crest is greater than first measured. In every case this is explained by some action by the property owner to extend the bluff crest by the construction of a bulkhead or by filling at the crest) .

5.3.3. Scenario.

- Determine which control point is to be visited.

• Locate the property using street address, or directions.
• If property is occupied, gain permission to conduct the work. If no one is home the survey crew can leave a card and call back, alert a neighbor about the activity and proceed, or leave a person at the car to interact with the owner should he or she return while work is being done. (It would be helpful to send a letter to all property owners prior to the field season.) In addition, the field crew should always be prepared to identify themselves.
• Identify landmarks using sketches, photographs, or other visual and verbal clues, and GPS technology if warranted.
• Perform the trilateration. This is easiest if there are three people doing the work; one each on a tape stationed at a landmark and one handling the unrolling tapes to the appropriate measurement on each one.
• Locate the intersect with a survey pin and verify that the pin is there using a metal detector and probe.
• Set up GPS and begin recording position if desired. (Current technology indicates that recording should be of sufficient duration to allow for maximum precision in computer determination of position during co-processing, usually no less than thirty "hits".
• Set up the transit over pin and measure distance.
• Record all information on GPS required by the attribute dictionary for the control point.
• Record control point number, date, time, GPS file number, distance, and remarks on standard field notebook as backup and as a ready job guide.
• Photograph site. Try to include tripod marking control point location as well as landmarks and condition of the site including the bluff crest. A panoramic camera is sometimes indicated to obtain a wide angle photograph of the site. Record the roll number and the frame number in the data dictionary or the field notebook or both.
• If precision positioning is possible without after-the-fact co-processing, use the GPS to record the intersect of the distance bearing line and the bluff crest. If desirable and possible, "walk" the bluff edge to record the geometry of the bluff crest. Note: This will only be possible if technology permits. Precise locationing will require "real time" coprocessing.
• Using the GPS, record the intersect of the distance bearing line, again recording for sufficient time to allow accurate positioning by co-processing.
Record all information on GPS required by the attribute dictionary for the bluff point.

Note: By the next time the field measurements are taken, GPS technology may be advanced to the degree that some of the above may become redundant, making the job of the survey crew that much easier.

5.4 Future Use of GIS and GPS Technology

Any attempt to predict the future of GIS and GPS technology should be based on trends and forecasts that seem plausible given the exponential growth of these technologies. Planners must face a future of on-going training to stay somewhat level. Those unwilling or unable to stay current will be left behind. Creative planners are driving the direction of these technologies forcing companies to stay competitive by accommodating the needs of the users.

Early on GIS applications emphasized mapping and data base management. Now, most applications have moved to modeling the interrelationships existing among mapped variables including cartographic modeling, spatial modeling and data mining. The latter would have some application in the coastal zone. Suppose rapid recession rates were compared to such driving variables as slope, elevation, and stratigraphy. The systems used to analyze these variables become dependent on the ability of the planner to provide sound information.

No planning office will survive without providing for direct and significant resources in human input and systems acquisition. DER currently has sufficient hardware and software to be current for five years providing resources are allocated for using it. Upgrades of ARC/INFO and ARCVIEW will become available to meet the increasing demands for data mining and spatial modeling. DER should become proficient with existing resources, stay as current as possible through outside training and workshops, and purchase appropriate system and equipment upgrades.

Advances in GPS technology will follow the government's decision to refrain from the existing policy of selective availability. Receivers currently on the market have sufficient power and precision to locate known points to within a few decimeters with co-processing. The cost of advanced equipment capable of real time co-processing will drop with increasing competition and demand. Planners can expect to have equipment within a few years that will enable survey certifiable results in the field for a fraction of the cost of units doing the same thing today.

DER has equipment capable of locating control points to the closest meter.

How much more accuracy is needed for this aspect of control point monitoring? Using GIS grade GPS receivers in the future will allow for surveyors to perform some tasks that are now considerably difficult. For example, I would suspect that altitude will become a very important attribute to collect in the field. With accurate altitude reading, the surveyor may determine accurate bluff heights, slope, and geometry.

Without the need to co-process or with real time co-processing available, the surveyor can walk the bluff lines and accurately display the result on the GIS data base. Repeated over time, this information will provide recession information for a shoreline reach spatial in the horizontal frame.

Section 6.0 Findings and Analysis

6.1 Introduction

The purpose and philosophy for establishing fixed control points are discussed in Section 3.0. The intent was to monitor established control points over time to determine recession rates and trends. It was inevitable that some of these points would be lost over time or otherwise be rendered nonfunctional for the purpose. It would be appropriate to discuss here the current condition of the system. It would be the prerogative of DER to replace or re-establish certain of these points according to need and circumstance. This section will also describe, for each viable point, the present situation with respect to bluff erosion.

DER should consider preparing a revised field book which would provide revised information for relocation of points by latitude and longitude or state plane coordinates fixed by GPS . Also, the drawings providing distance and bearing information should be redrawn, taking into account corrections made during the 1994 field season. It would be most appropriate to enter this information into the DER control point GIS data base.

6.2 Condition of DER Control Points

The following is a discussion of control points that have been lost, relocated, or otherwise need attention.

0.0 This point was established in 1986. This land was occupied until the late 70's by cottages built on land leased from U.S. Steel. Their intent to build a mill on the site forced the abandonment and destruction of these cottages. The point was located on a drive to one of these abandoned sites. Between 1989 and 1994, the land was given over to the Pennsylvania Game Commission. The point location was destroyed by the construction of a small parking lot used to access a memorial park. The approximate position of the pin was determined and a measurement made, although the actual pin was never found. The point can be abandoned or re-established with information provided in DER field books. A new control point 0.1, is established using the memorial rock in the park.

0.1 See above. The point should be incorporated into DER field books.

1.0 This site was established in 1982. The site was abandoned by 1986 due to the loss of landmarks to erosion. A new site, 1.1, was established in 1986 to replace it.

1.1 Rapid recession on the site forced a relocation of the control point. (See DER field book.) The point remains viable.

2.0 This point could not be found during the 1994 field season. It is likely that it was lost due to bluff erosion. Attempts should be made to either relocate the point, or establish a new one based on a recoverable landmark.

3.5 This site is being cleared. If a permanent structure is built, this point could be lost.

7.5 This is a very low lying area, more a beach than a bluff. Construction of a sea wall at this site lakeward of the original line is probably suitable cause for abandoning the control point. Since the new line is lakeward the site shows a negative recession rate. This data should not be used for computing overall recession rates.

11.0 This is a very active site. Quite possibly the control point will be lost by the next visit. It is easily re-established however, using landmarks.

26.0 This point was never established. It falls in the broad, low lying mouth of Walnut Creek.

31.5 It is likely that this wooded site will have been developed by the next visit.

44.0 This site was not monitored after 1986. A seawall maintained by International Paper Company precludes recession here. A control point (44.2) was established in 1986 to replace it.

49.5 This control point was lost due to the construction of a house over the location.

51.0 This control point was never established due to property owner resistance.

52.5 The control point was re-established in 1989. The original point was lost due to construction on the site.

57.0 Permission to monitor this site was refused in 1994.

62.0 This control point was never established.

70.0 The control point was lost due to the construction of Safe Harbor Marina.

70.5 This control point was never established.

71.5 This control point was never established (Twenty Mile Creek).

72.0 This control point was never established (Twenty Mile Creek).

Summary:

Total Number of Points Possible on 1982 Grid		63
Total Number of Points Possible on 1986 Grid		64
Total		127
Total Number of Points Never Established		6
Total Number of Points Abandoned		10
Erosion	3	
Construction	4	
Other	3	
Total Number of Points Recovered		4
Total Number of Viable Points		115
Total Number of Points to be Recovered (c.p. #'s 2.0, 57.0, 49.5, 51.0, 70.0)		5

In addition to the points lost, there are a number of points that could be lost, some to erosion and some to construction. The DER should make property owners aware of their responsibility for maintaining the markers much as underground utilities are protected. The DER discussed this in 1982 and 1986 but never followed through on establishing a policy.

6.3 Discussion of Recession on Established Control Points

6.3.1 Analysis of Recession Rates: DER Control Points 1982-1994 and 1986-1994

Depending on time of year actual measurements were taken, the number of years separating the measurements may vary from 7.3 years to 12.3 years. The analysis of recession rates divides the total distance difference measured by the actual number of months separating the measurements (converted to years).

The average recession rate for all control points over the respective periods of record is .8957 feet per year. The number of points exceeding the average recession rate is eight. All control points fall within one standard deviation above and below the mean. The rate is compared with the recession rate previously used by DER based on measurements of aerial photographs and reported in Knuth and Crowe, 1975. That rate for eighty-nine points measured was 1.075 feet per year. With anomalies removed the recession reported for the period 1938 to 1975 was .874 feet per year based on eighty-two sites. The 1982, 1986, and 1994 studies used survey measurements based on fixed monuments. This procedure is considered accurate. The percentage of error in the 1975 study is determined to be less than 2%.

Data exists for forty-five control points measured since 1982. A trend in recession rates for these points is based on measurements taken in 1982, 1986, and 1994. A trend analysis 1982 to 1994 reveals that for five of the forty-five points measured the recession rate is increasing. For twenty-seven of the forty-five control points measured, the recession rate is decreasing. Thirteen of the control point show no increase or decrease. The thirteen control points in this category are sites for which no recession is recorded over the twelve year period. Based on an analysis of the original forty-five DER control points, recession rates along the Lake Erie shore are decreasing. Recession continues but the rate of loss is reduced.

When all DER control points are considered (including the above) the trend is as follows: increasing rate of recession-27 (23.7%) , decreasing rate of recession-59 (51.8%), and 28 (24.6%) remain the same (no change or no recession). Figure 6.1 is a bar graph of recession rates distributed from left (western county) to right (eastern county). Recession rates are, on average, higher west of Presque Isle than they are east. Some exceptions for the eastern trend are found in the high bluffs between Sixteen Mile Creek and Twenty Mile Creek. The height of the bluffs and the high erodibility of the beach ridges exposed in the bluff face contribute to this increased recession.

In general, the lower recession rates in the eastern reach are attributed to the bedrock exposed over much of the reach. The western reach, lacking the bedrock exposure has an increased amount of recession. Overall, the bluffs in the eastern reach are lower in height, which also reduces the rate of recession.

After the generalities of bluff height and the presence or absence of bedrock at the base of the bluff are made, variations in the rates of recession are made by the following sets of premises. In general, a bluff that has been eroding in response to high lake levels that have since receded is closer, over time to reaching a stable angle. Recession rates will drop as stability increases. This may explain the fact that over fifty percent of the bluffs are experiencing less recession 1986-1994 than they were 1982-1986. After a decade of high lake levels, the lake levels began to drop after 1976. It took a decade for the bluff crest to respond to the oversteepening produced by the erosion of the bluff base. The control points experiencing increased recession are harder to explain.

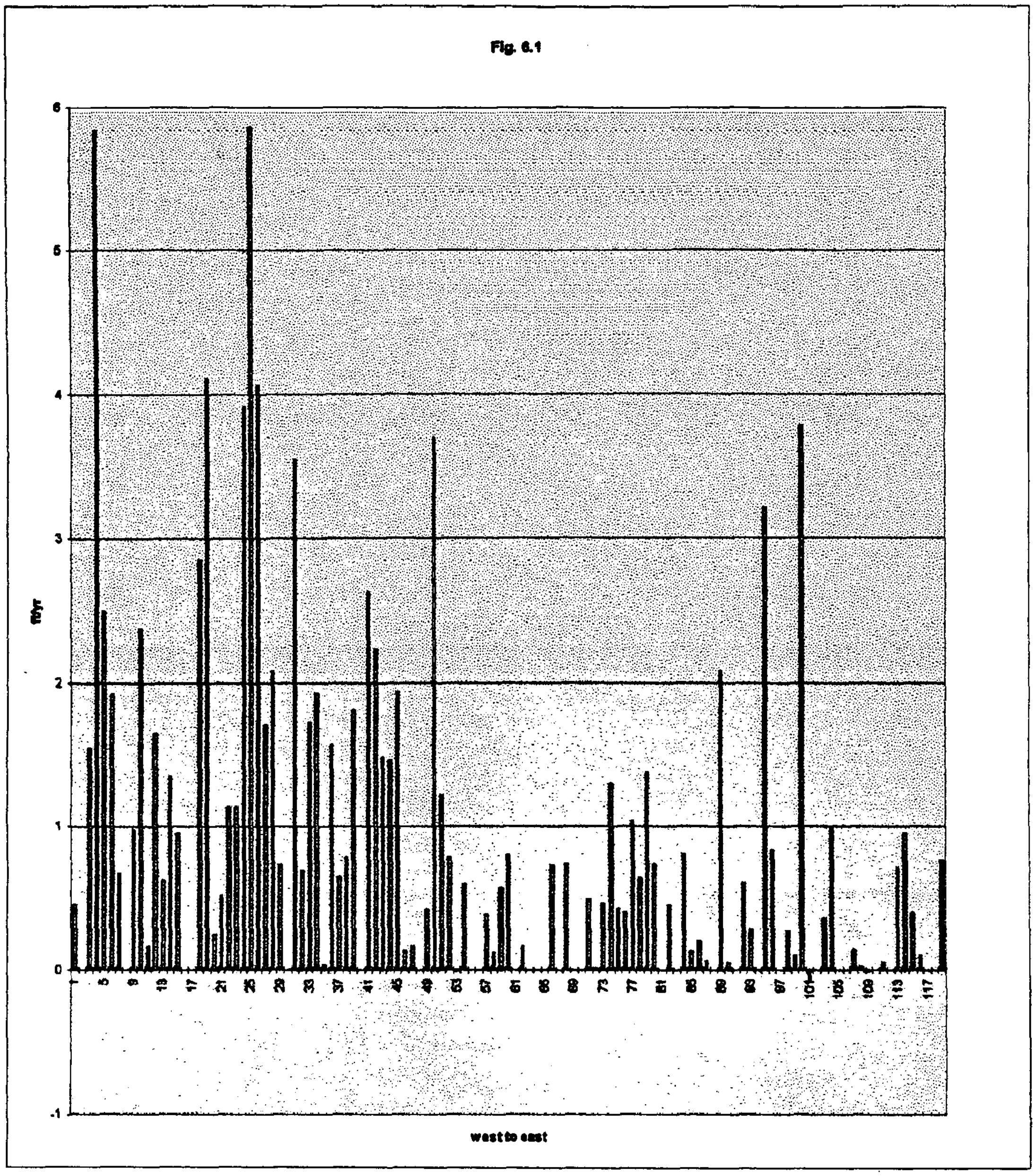
Appendix B contains recession rate data expressed as graphs for each control point showing trends in recession rate over time. Figure 6.2 shows the long term recession rates over all points. Figure 6.2 also shows the actual amount of recession expressed in feet. Figure 6.3 is a bar graph of the number of feet lost by each control point.

6.3.2. DER Control Points Experiencing an Increase in Recession Rates.

Of the control points showing an increase in recession rates, fifteen are in an order of magnitude too small to be significant. The remaining points are significant either because of a dramatic increase in recession or because the baseline recession is large. The following control points are discussed individually in an attempt to understand why the rates are increasing.

4.5 (See DER Aerial Oblique 0194 frame 35) As can be seen on the photo, the bluff is linear with two large incisions, one in front of the house and the other to the east on the left of the picture. The control point can be seen on the photo; a utility pole one hundred feet plus north of the road. On a line normal to the bluff it intersects the incision on the western flank. The abnormal recession here, fourteen feet in six years, is due to the opening of this incision on a bluff that was already receding.

12.5 (See DER Aerial Oblique 0394 frame 14) The control point is just about in the



Recession Rates in Ft/Yr

center of the picture just west of the large ravine. These are high bluffs capped with a lacustrine layer very prone to slumping. Recession along this entire reach, from Crooked Creek on the west to Elk Creek on the east continues at a high rate. The rate on this site increased from 3.65 ft/yr to 4.27 ft/yr 1989 to 1994.

13.5 (See DER Aerial Oblique 0394 Frame 18) See Above. The recession rate here went from .54 ft/yr to 2.95 ft/yr.

17.5 (See DER Aerial Oblique 0494 Frame 12) This is a high, actively receding bluff with a sandy layer on top. Recession is uniform along the reach but at this site it jumped from .06 ft/yr to 2.42 ft/yr. Given the otherwise uniformity of recession and the lack of any causal influence, the increase may result from inaccuracies in the 1989 survey.

18.5 (See DER Aerial Oblique 0494 Frame 18) The control point lies on a line parallel with the line of pines on the west side of the developed property, just adjacent to the hardwood tree. Wasting along the line of the bluff crest is producing a very incised character to the crestline. The increase in recession rate is due to the opening of one of these incisions and probably is a time-specific event.

21.5 (See DER Aerial Oblique 0594 Frame 7) This is a high bluff, actively receding. The increase in recession on this site is due to oversteepening in the sandy top layer produced by wasting in the till layers below. Notice the steep angle in the top layer compared to the rest of the slope below. The control point falls between the line of cottages in the center of the picture.

22 (See DER Aerial Oblique 0594 Frame 13) See above. The control point is in the woods in the center of the frame. Note the large incisions in the bluff. The top layers in this reach are responding dramatically to rapid erosion of the lower layers. The recession rate jumped rom 0.00 ft/yr to 3.29 ft/yr. 1989 to 1994.

24.5 (See DER Aerial Oblique 0594 Frame 34) See above. This is a rapidly receding bluff that has increased its rate of recession from 3.25 ft/yr to 3.95 ft/yr in the time period 1989 to 1994. Notice the downed trees. Also notice the lineations in the top layer. This site has lost over 19 feet since 1989.

33 (See DER Aerial Oblique Frame 7) The picture speaks for itself. This is a very

active site. Groins built on beaches to the west have eliminated much of the beach building materials that ordinarily would have nourished this beach. The presence of cottages at the base of the bluff is an indication that beaches here were historically very wide. The wide beaches protected the bluffs behind. These bluffs have become increasingly unstable as a consequence of development in the landward area. When the stabilizing influence of the beach was removed, the bluffs responded appropriately. The site has lost nine feet most of it since 1989.

55.5 (See DER Aerial Oblique 1494 Frame 28) The control point is in the yard of the house on the right in the right center of the frame. As can be seen the yard is "in the air" flanked on on side by a wooded ravine and on the other by a wooded upper slope. The bluff here will continue to adjust to at least the angle of the bluff faces east and west. The site lost fifteen feet between1989 and 1994.

59 (See DER Aerial Oblique 1694 Frame 6) These are very high bluffs with very unstable sandy layers at the crest. The increase in recession here is due to drilling (gas) activity. The control point is associated with the deep reentrant to the left of center in the frame. These cirque-like features open up on the bluffs on this reach in response to loss of shear strength in the sands. In this case the contributory factor is associated with the well and trenches dug for pipe. The site lost twenty - four feet between 1989 and 1994.

61.5 (See DER Aerial Oblique 1794 Frame 1) Glacial beach sands are prominently exposed in the top forty feet of bluff. These are some of the most unstable bluffs on the shoreline. Once the base is corrupted by high water levels, or some other destabilizing influence, these bluffs begin to fail. This site has lost twenty-six feet since 1989. A house used to sit in front of the garage.

		CPNUM	RECESS	YEARS	FT/YR	M/YR	CI	CD	CS
		0	3.5	7.74	0.45	0.14		X	
		0.1	0	0	0	0			
		0.5	12	7.74	1.55	0.47		X	
		1.1	45	7.72	5.83	1.78		X	
		1.5	19.34	7.73	2.5	0.76		X	
		2.5	22.58	11.79	1.92	0.58		X	
		3	8.25	12.36	0.67	0.2		X	
		3.5	0	7.75	0	0			X
		4	12.17	12.37	0.98	0.3		X	
		4.5	18.42	7.75	2.38	0.72	X		
		5	2	12.36	0.16	0.05	X		
		5.5	12.75	7.73	1.65	0.5		X	
		6	7.83	12.36	0.63	0.19		X	
		6.5	10.5	7.73	1.36	0.41		X	
		7	11.7	12.36	0.95	0.29		X	
		7.5		7.73	0	0			
		8	0	12.35	0	0			X
		8.5	22	7.72	2.85	0.87		X	
		9	50.75	12.34	4.11	1.25		X	
		9.5	1.83	7.27	0.25	0.08		X	
		10	4	7.72	0.52	0.16		X	
		10.5	8.33	7.3	1.14	0.35		X	
		11	14	12.31	1.14	0.35		X	
		11.5	29	7.42	3.91	1.19		X	
		12	43.5	7.42	5.86	1.79		X	
		12.5	29.5	7.27	4.06	1.24	X		
		13	21	12.28	1.71	0.52		X	
		13.5	16	7.69	2.08	0.63	X		
		14	9	12.34	0.73	0.22		X	
		14.5	0	7.72	0	0			X
		15	27.17	7.68	3.54	1.08		X	
		15.5	8.25	11.71	0.7	0.21		X	
		16	21.25	12.25	1.73	0.53		X	
		16.5	15.25	7.88	1.93	0.59		X	
		17	0.5	12.3	0.04	0.01			X
		17.5	12.09	7.68	1.57	0.48	X		
		18	8	12.23	0.65	0.2		X	
		18.5	6	7.69	0.78	0.24	X		
		19	22.33	12.31	1.81	0.55		X	
		19.5	0	7.25	0	0			X
		20	32.33	12.31	2.63	0.8		X	
		20.5	17.17	7.66	2.24	0.68		X	
		21	18.33	12.29	1.49	0.45		X	
		21.5	11.25	7.66	1.47	0.45	X		
		22	23.7	12.21	1.94	0.59	X		
		22.5	0.92	7.3	0.13	0.04		X	
		23	2	12.29	0.16	0.05		X	
		23.5	0	7.64	0	0			X
		24	5	11.96	0.42	0.13			X
		24.5	28.33	7.68	3.69	1.12	X		
		25	15	12.25	1.22	0.37		X	
		25.5	6	7.68	0.78	0.24		X	
		26.5	-0.08	7.66	-0.01	0		X	
		27	7.33	12.31	0.6	0.18	X		
		27.5		7.68	0	0			
		28	0	12.25	0	0			X
		28.5	3	7.8	0.38	0.12		X	
		29	1.5	12.24	0.12	0.04			X
		29.5	4.42	7.8	0.57	0.17			X
		30	10	12.45	0.8	0.24		X	

Figure 6.2

Recession Rates and Trends by Control Point

Recession in Feet

Years= Period of Record

CI= Recession Rate Increasing

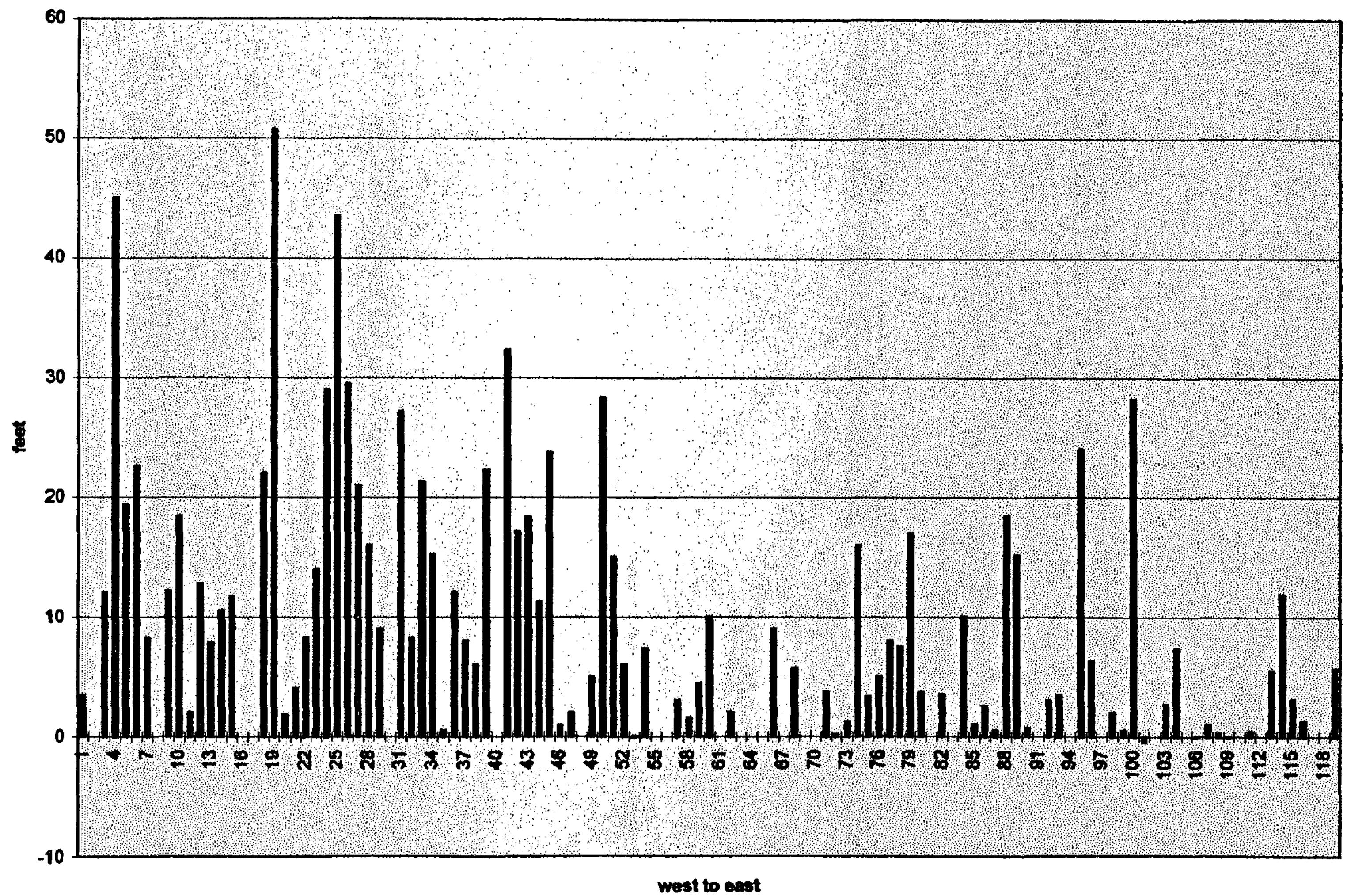
CD= Recession Rate Decreasing

CS=Recession Rate Static

		CPNUM	RECESS	YEARS	FT/YR	M/YR	CI	CD	CS
		30.5	0	7.29	0	0			X
		31	2	12.32	0.16	0.05		X	
		31.5	0	7.67	0	0		X	
		32	0	12.28	0	0			X
		32.5	0	7.67	0	0			X
		33	9	12.31	0.73	0.22	X		
		33.5	0	7.65	0	0			X
		44.2	5.67	7.69	0.74	0.22		X	
		44.5	0	7.79	0	0			X
		45	0	12.42	0	0			X
		45.5	3.75	7.69	0.49	0.15		X	
		46	0.17	12.32	0.01	0			X
		46.5	1.25	2.73	0.46	0.14		X	
		47	16	12.32	1.3	0.4		X	
		47.5	3.33	7.69	0.43	0.13	X		
		48	5	12.32	0.41	0.12	X		
		48.5	8	7.69	1.04	0.32		X	
		49	7.5	11.74	0.64	0.19		X	
		50	17	12.32	1.38	0.42		X	
		50.5	3.67	4.96	0.74	0.23	X		
		51.5		7.7	0	0			
		52	3.5	7.71	0.45	0.14		X	
		52.5	0	7.7	0	0			
		53	10	12.28	0.81	0.25		X	
		53.5	1	7.71	0.13	0.04		X	
		54	2.5	12.35	0.2	0.06		X	
		54.5	0.5	7.7	0.06	0.02		X	
		55	18.5	12.25	0	0			X
		55.5	15.17	7.31	2.08	0.63	X		
		56	0.67	12.33	0.05	0.02			X
		56.5	0	4.69	0	0			X
		57.5	3	4.94	0.61	0.19	X		
		58	3.5	12.33	0.28	0.09		X	
		58.5	0	7.39	0	0			X
		59	24	7.48	3.21	0.98	X		
		59.5	6.3	7.48	0.84	0.26	X		
		60	0	7.48	0	0	X		
		60.5	2	7.48	0.27	0.08		X	
		61	0.5	4.95	0.1	0.03	X		
		61.5	28.25	7.48	3.78	1.15	X		
		62	-0.5	7.4	-0.07	-0.02	X		
		63	0	11.88	0	0			X
		63.5	2.67	7.4	0.36	0.11		X	
		64	7.33	7.4	0.99	0.3	X		
		64.5	0	7.4	0	0			X
		65	-0.03	7.48	0	0			X
		65.5	1	7.39	0.14	0.04		X	
		66	0.25	12.33	0.02	0.01			X
		66.5	-0.09	7.39	-0.01	0			X
		67	0	12.33	0	0			X
		67.5	0.42	7.7	0.05	0.02		X	
		68	0	12.33	0	0			X
		68.5	5.5	7.7	0.71	0.22		X	
		69	11.83	12.33	0.96	0.29		X	
		69.5	3.08	7.7	0.4	0.12	X		
		71	1.25	12.33	0.1	0.03		X	
		72.5	0	7.7	0	0	X		
		73	0	7.39	0	0	X		
		73.5	5.67	7.39	0.77	0.23	X		

Figure 6-2 (cont.)

Fig. 6.3 Recession



Recession in Actual Amount of Loss in Feet

Section 7.0 Recommendations/Conclusions

7.1 Bathymetry

A general offshore bathymetry of the southern shore of Lake Erie is available from navigational charts of Lake Erie available from NOAA. These charts are updated periodically and are used primarily for navigation. Nearshore bathymetry is generally only inferred since detailed soundings are not taken in the inshore areas.

Topographic maps of the southern shore of Lake Erie are available. They only infer offshore bathymetry and should not be considered accurate since no soundings are taken. Topographic maps are produced by the United States Geological Survey while navigational charts are produced by the National Oceanographic Atmospheric Administration. The land based topography is determined from Coast and Geodetic Survey datum while the bathymetry uses IGLD, 1955. The two datums are several feet apart. The problem of using either for nearshore bathymetry becomes apparent.

As a result accurate precise nearshore bathymetry must be accomplished using bottom recording devices such as side scan sonar, fathometer or similar device on-board or towed behind small craft able to navigate in the shallows along shore. Accurate positioning is key to obtaining usable data.

In 1981 the then Pennsylvania Coastal Zone Management Program funded a geotechnical study of the Pennsylvania portion of the open water shoreline of Lake Erie. The study included an examination of offshore bathymetry offshore of control points established on the bluffs spaced one kilometer apart from the Ohio border to the new York border exclusive of Presque Isle and the shoreline of Presque Isle Bay. From that report:

A series of bottom profiles were obtained using a recording sonar device at each designated control point. The traverse was made shore normal over an approximate distance of four hundred yards to an average depth of twenty feet for the reach west of Presque Isle and thirty feet for the reach east of Presque Isle.

Shore markers placed at all control points were used to provide the location for the beginning of each profile line. In the absence of accurate positioning anywhere along the transect the boat was operated at 1500 rpm to maintain a constant speed and each transect was run under calm conditions. At the estimated end of each run a range finder was used to fix the position of the boat with respect to the distance offshore. A crew onshore in radio contact with the boat enabled the captain to keep a constant bearing on the transect. The distance obtained was transferred to the chart.

In the lab the chart was transferred to a grid and the distances stretched to fit the chosen scale. At intervals the depth from the chart was transferred to the chart producing a profile line for the bottom. The profiles were included in the report entitled *A Geotechnical Investigation of the Coastal Bluffs of Erie County, Pennsylvania* (Knuth, 1983).

The profiles obtained were as accurate as the methodology permitted. Close control on positioning was not at a technical or economic level in 1981 to permit exact positioning. Using modern, and now inexpensive but highly accurate positioning (GPS) in combination with a simple recording fathometer, the offshore bathymetry can and should be repeated. The most important reason for understanding the exact configuration of the bottom is the hypothesis that the bottom is controlling wave energy, concentrating it in places while producing a "shadow effect" in others; in effect producing different rates of shoreline retreat.

Recommendation: Conduct a full bathymetric examination of the open water reaches of the Pennsylvania shoreline using GPS and bottom recording technology. At a minimum the profiles should be established offshore of each established DER recession control point. If affordable side scan sonar should be employed to provide a comprehensive "picture" of the bottom over a wide transect line.

7.2 Details of Bluff Stratigraphy

In the geotechnical report referenced above an attempt was made to understand the stratigraphy exposed along the bluffs east and west of Presque Isle. Nothing impacts on recession rates as much as the nature (erodibility) of the bluff itself. In addition, these eroding bluffs provide most of the sediment for alongshore deposition.

From that report:

The bedrock exposures at the base of some bluffs east and west of Presque Isle are of the Canadaway Formation, Middle Upper Devonian in age and are variously described as: alternating shales and sandstones including the Portage Formation of Northwestern Pennsylvania; undifferentiated shales underlying quaternary deposits consisting of poorly differentiated sequences of interbedded shales, claystones, siltstones and sandstones; Upper Devonian shales with interbedded siltstones.

The bedrock exposures are important for three reasons. First, these exposures present a resistant surface to wave energy, deflecting energy downward and scouring sediment from their base. Beaches build along these reaches only where the supply of sediment can overcome the offshore loss. Secondly, these exposures provide some of the coarser material (shingles) important in beach formation. Thirdly, linear joints in the shales exposed to storm waves are expanded producing incised or cuspate forms seen along some reaches east of Presque Isle.

The quaternary units above bedrock vary. Some or all may be present in any section. Glacial Till- clays and silts with associated coarser fragments, resulting from sediment deposition (Wisconsin age) Some of the tills contain localized pockets of glacio-lacustrine deposits formed by deposits in small lakes or ponds. Lacustrine Deposits- thinly interbedded clayey silts and silty clays of proglacial lakes Stand Deposits- two general units (sand and gravels and sands and silty sands) associated with previous shorelines of proglacial lakes Alluvial Deposits- sandy silts and clays with variable amounts of sand and gravel and minor pockets of organic soil.

Preliminary attempts were made to map these units during the geotechnical investigations conducted 1981-1983. Sections were described for each of the recessional control points established at the time (Note: These points were established on a one kilometer grid from the Ohio Border northeastward along the shore to the New York Border. They were numbered 1-33 and 44-73. Points 34-43 are on the bluffs of Presque Isle Bay and were never established on the ground. Accurate mapping of these sections requires more man hours than was available at the time and the descriptions were cursory as a result.)

Recommendation: There is direct cause and effect relationship between the nature of bluff materials and the degree of erodibility. In addition, the geometry of the face and the relative success of stabilization are related to both bluff height and recession. Finally, more forms of mass wasting e.g. slumping are more prevalent in some materials than others.

A comprehensive examination of bluff stratigraphy should be undertaken. At a minimum, sections should be mapped corresponding to each of the established DER recession control points. This mapping may be made in conjunction with mapping the geometry of the bluff face recommended below.

7.3 Bluff Geometry (Crest and Face)

In 1981 the geometry of the bluff face at each established DER control point was mapped using the following technique. A one-half inch nylon rope 250 feet in length was calibrated in one meter units. The rope was anchored at the bluff crest and drawn taut on the beach below. The natural sag was not determined but was considered to be minor. The line was permitted to touch irregularities on the face but was not permitted to be deformed by the irregularity. A telescoping stadia rod was held plumb to each meter tick on the rope and each measurement recorded. In the lab the measurements were transferred to a graph, producing a profile of the bluff face. The bluff angle was determined in the field with the Abney level. This sounds simple but is deceptive. High bluffs with irregular faces and ample vegetation produced some interesting challenges. The results are, however, considered very accurate.

Recommendation:

This procedure should be repeated to determine the changes in the geometry since 1981. In addition, the procedure should be done for all recessional control points not included in the original study to provide a base line for future study. Bluff recession is episodic. Understanding the geometry may help in predicting where recessional events are most likely to occur. During the same study the geometry of the bluff crest was established. This plan view of the crest is helpful in understanding the nature of recession at the crest. Recession can produce crestlines that are linear, incised, or irregular. The geometry of the crest was determined by the following technique.

A plane table was set over each established control point and plumbed to the pin beneath. A telescopic alidade was mounted on the table over a mylar surface. Beginning with shot to magnetic north for each site rays were shot east and west of this common line depending on conditions and orientation of the bluff line at the site. The original mylars are preserved at Edinboro University of Pennsylvania. In the lab the information was transferred to graphs and made part of the overall record of the site.

Recommendation:

As with the bluff face geometry, the process should be repeated for recessional 1981 control points and done for the first time on all recessional points added since 1981. Using the base line provided in the earlier study important information on the nature of bluff retreat can be easily had. It may answer questions such as: Is the recession parallel or irregular?

7.4 Regional Hydrology

Ground water contributes to bluff instability and is perhaps one of the most important variables. Although there have been regional ground water studies completed, these studies provide information about water resources that in most cases lie well below the zone having impact on the bluff face. The author knows of no regional shallow ground water investigation having been completed for any reach of Pennsylvania shoreline. The DER provided funding in 1981 to conduct a dewatering project on a bluff in Fairview Township. The construction phase of the project was to be followed up by a long term analysis of the effectiveness of the dewaterting design. Failure on the part of DER to monitor the project wasted an opportunity to add a substantial amount of knowledge about regional shallow ground water hydrology.

Recommendation:

A comprehensive ground water study for the entire shoreline would be prohibitively expensive. At a minimum, two ground water studies should be conducted. One should be conducted on an area undergoing substantial change as a result of development. The Baldwin site in Millcreek Township would be ideal. Another study should be directed to a site undergoing recessional losses that appear to be driven mainly by ground water discharge on the upper bluff face.

7.5 Comprehensive Monitoring Program

Initial monitoring sites were established in 1982. These sites have since been revisited in 1886, 1989, and 1994. Supplemental sites were established in 1986. These sites were revisited in 1989 and 1994. Legislation provides for sites to monitored every five years. Monitoring all sites every five years can be expensive. In addition, there would be no field investigations in the interim. Monitoring every site every year (a recommendation of the International Joint Commission) may not make sense either since because some increments of loss are too small to be measured over such a short period of time.

Recommendation:

A field reconnaissance program should be instituted that would put investigators in the field every year. During each field season, 20% of the recessional control points would be visited. The first year would involve measurements of those sites demonstrating the highest amount of activity during the 1994 field season. The second season would revisit another 20% and so on for five years. The procedure would be in compliance with the law Bluff Recessiona and Setback Act. The most active sites could also be monitored yearly and DER staff would gain some familiarity with a sampling of recessional sites on an annual basis. The annual investigation could also involve conducting some bluff geometry studies or some stratigraphic mapping.

7.6 Additions to GIS Database

Supplemental Control Points

The original grid established for recession rate monitoring was regular in the sense that control points were established every one-half kilometer. Some stretching east and west of the grid point was accepted to overcome access or topographic problems. In many cases control points are located adjacent to sites where the recession rate is dramatically different, either higher or lower. It could be statistically misleading to be measuring a site that registers little annual recession when 50 meters away that bluff is receding rapidly.

Recommendation:

There should be a higher concentration of recession monitoring points where:

- recession rates are high over a substantial reach (two or more kilometers)

- extensive development is underway or planned

- where rapid recession and development coincide

Data from these supplemental sites would be included in the data base to determine long term recession for that reach only. Care would have to be taken to not bias the overall recession rates for the entire reach. The reason the grid system was established was to prevent such bias. Using the GIS data base might make it possible to interact the data in any number of ways however. For example

- What is the average recession rate for those bluffs that are rapidly receding?

- What is the average recession rate for those bluffs that are rapidly receding and are also highly developed?

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